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A SEMI-QUARTERLY JOURNAL PUBLISHED BY
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ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. 46 JANUARY–FEBRUARY, 1951 No. 1

NOTES ON THE MANGANESE ORES OF BRAZIL.[1]

C. F. PARK, JR., J. V. N. DORR, II, P. W. GUILD,
AND A. L. M. BARBOSA.

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ABSTRACT.

Brazil has been a small but consistent source of manganese ore for world markets during the last five decades. Production both for export and for domestic use is likely to increase.

Deposits can be classified into syngenetic (the primary manganese sediments in iron formation at Urucum) and epigenetic. The epigenetic deposits can be further subdivided into four classes:

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(a) The Queluz or Morro da Mina type, in which the manganese oxide ore has been derived by weathering processes from a manganese silicate-carbonate-sulfide protore.

(b) The Lagôa Grande type, enclosed in itabirite, in which lean manganiferous horizons in the metamorphosed iron formation have been leached and the manganese concentrated by weathering processes.

(c) Deposits in slightly manganiferous rocks of various types in which the manganese has been concentrated by weathering processes.

(d) Deposits in barren rocks into which manganese oxides have been introduced from unknown sources.

It is probable that the Lagôa Grande type is closely related in ultimate origin to the Urucum type, although the regional metamorphism suffered by the former obscures relations.

The Urucum deposits and two deposits of the Morro da Mina type have large reserves of export-grade ore. Many deposits of the Lagôa Grande type are known and the aggregate reserves are large, although their grade makes them more suitable for domestic than for export use. Deposits of the other two types are numerous but small, and their grade seems to consign most ore from these deposits to the domestic market.

INTRODUCTION.

For many years manganese ores have been a valuable Brazilian export commodity, and the steel industry in the United States has come to depend upon Brazil for a small but steady output of this material. Until recently the Brazilian iron and steel production came from small charcoal furnaces and required very little manganese, but with the opening of the large modern charcoal plant of Cia. Siderurgica Belgo-Mineira at Monlevade, Minas Gerais, and the National Steel Mills at Volta Redonda, the demand for manganese to be used in domestic industry has increased.

The increase in steel production, brought about by and in turn stimulating the rapid industrialization of Brazil, has caused many thoughtful and responsible Brazilians to become concerned about the adequacy of future manganese supplies for their own use. Withholding of much of the central Minas Gerais manganiferous areas from export production has been discussed. With the exception of Morro da Mina much of the central Minas Gerais ore is too low-grade to permit large-scale export even though it is satisfactory for domestic purposes.

The unsettled condition of world affairs and the desire of the democracies to obtain a major source of manganese ore in the Western Hemisphere have also stimulated demand for Brazilian ore. This paper presents data and hypotheses on the genesis of the ores and describes a few of the known deposits in the hope that an understanding of the modes of origin will help future exploration.

Although manganese ore deposits are known in many parts of Brazil, most of the production to date has come from central Minas Gerais (Fig. 1). Smaller amounts of ore have been shipped from the Serra de Jacobina and Santo António de Jesús (Nazaré) districts of the State of Bahia, and from Morro do Urucum, near Corumbá, in western Mato Grosso. The Urucum district is one of the large deposits of the world, but its development is retarded by the long distance to market and by the fact that the ore contains about 11

per cent of iron. A recent discovery (1941) in the Serra do Navio, Federal Territory of Amapá, gives promise of large amounts of ore, although the work to date has been too limited to prove the value of the property (30, 32).[2] Other deposits have been described in the States of Maranhão, Pará, Goiaz, Pernambuco, Rio de Janeiro, Rio Grande do Norte, São Paulo, and Santa

FIG. 1. Index map of Brazil, showing the location of the principal manganese ore deposits in relation to the cities of Rio de Janeiro and São Paulo.

Catarina. The closely grouped deposits of central Minas Gerais are shown on a separate map (Fig. 2).

GENETIC CLASSIFICATION.

The only manganese ores sought are the oxides, which consist predominantly of pyrolusite and one or more of the minerals of the psilomelane group. Mix-

[2] Figures in parentheses refer to Bibliography at end of paper.

tures of silicate, carbonate, and sulfide (?) are widely distributed, and, where deeply weathered, form source rocks for ore. Rhodonite and the manganese garnet spessartite are present in many deposits; tephroite and neotocite have been reported from Minas Gerais, and it is likely that other silicates will be found if thorough study is made of the unaltered rock. Manganese carbonates form part of the protore at Morro da Mina, near Lafaiete, in central Minas Gerais. In samples of fresh silicate rock from the lowest workings at Morro da Mina, an appreciable part of the matrix between the silicate and carbonate

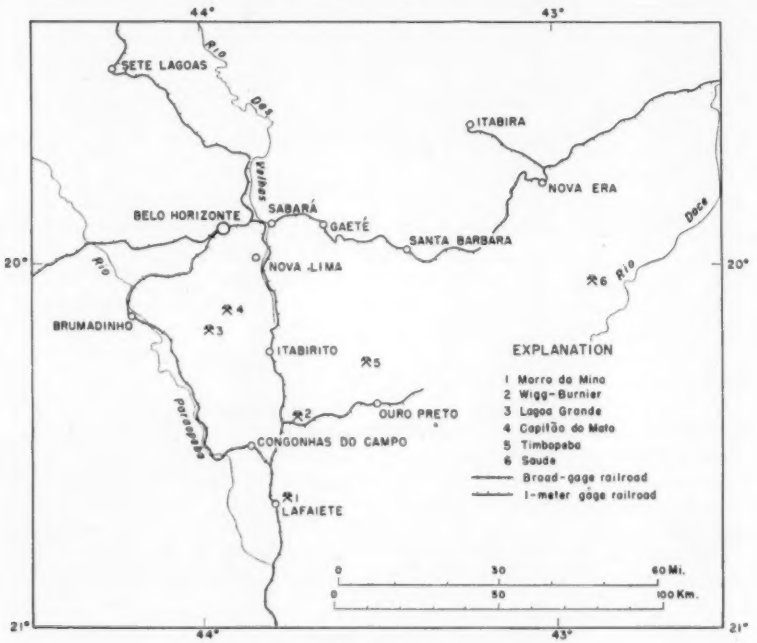


FIG. 2. Index map of central Minas Gerais.

grains is alabandite, the manganese sulfide. As alabandite readily decomposes to the oxides, it may be more widespread than realized. Any mineral, such as pyroxene or amphibole, that contains a small amount of manganese decomposes under tropical weathering conditions, and the manganese oxides may be concentrated in the outcrops.

Genetically the manganese oxide deposits fall naturally into two classes: (a) original sedimentary beds, and (b) deposits formed by weathering processes and the superficial enrichment of manganese-bearing protore. Original sedimentary beds may or may not be enriched by supergene processes; deposits

such as those of Morro do Urucum are thought to have changed but little in composition from the material as laid down. The deposits enriched by superficial agencies are divided into four types:

1. Deposits derived from unknown manganese minerals, probably of primary manganese oxides, in itabirite.
2. Deposits formed by the oxidation of manganese silicate-carbonate-sulfide bodies.
3. Deposits formed by the oxidation of other rocks that contain manganese.
4. Deposits formed in non-manganiferous rocks or soils by solutions transporting manganese from unknown sources.

ORIGINAL SEDIMENTARY BEDS.

The manganese deposits of Morro do Urucum lie about 25 kilometers south of the city of Corumbá, in the State of Mato Grosso (27, 28, 29). These deposits were formed as sediments contemporaneously with the enclosing rocks. Other deposits, particularly those in the itabirite in Minas Gerais, may also have originated as sediments, but they have been so metamorphosed and weathered that their original character is obscure.

The Urucum deposits, thought to be of early Paleozoic age, are at or near the base of the Band'Alta formation, a member of the Jacadigo series. The formation, not less than 300 meters thick, is characteristic iron-formation—thin alternating layers (¼ to 2 inches thick) of hematite and chert averaging about 45 percent iron. The Band'Alta formation resembles the characteristic taconite in the Lake Superior region and the banded ironstones in many places throughout the world, though no iron carbonates have been found in Brazil. The genesis of iron formation has been much debated and is not clearly understood. Most careful workers agree that the materials have been deposited as chemical sediments. At Urucum, Dorr (28) considers that both silica and iron may have been deposited as hydrogels, and thinks that the Band'Alta formation was deposited in a large epicontinental basin, possibly under arid conditions (28). No evidence of volcanic activity has been found near Urucum, and the ultimate source of such tremendous quantities of unusual sediments is unknown, unless, as pointed out by Moore and Maynard (13), the decay and solution on old peneplained land masses will yield sufficient materials.

In Morro do Urucum a persistent bed of manganese oxides crops out at the base of the Band'Alta formation. This bed ranges in thickness from 20 centimeters to 6 meters and averages perhaps 2 meters. A similar bed, 2 meters or less in thickness, is separated from the lower one by 30 to 45 meters of iron formation. Other discontinuous lenticular bodies of manganese oxides are found in the lower third of the Band'Alta formation. The fact that the manganese beds occur in the iron formation has led to the belief that the manganese is genetically related to the iron and silica, and to the further belief that the manganese, like the iron and silica, was precipitated in colloidal form as the hydrous oxide. Above and below each bed and lens of manganese oxide are beds of clastic materials, probably arkose, from a few centimeters to 2 meters

thick. The presence of these clastic beds so closely associated with the manganese oxides, intercalated in a thick section of chemical sediments, indicates an abrupt but very temporary change from chemical to clastic sedimentation. It is probable that this changing environment somehow inhibited the precipitation of the iron and silica and at the same time encouraged the precipitation of the manganese. The iron-manganese ratio of the manganiferous beds is about 0.24:1; the ratio in the enclosing iron formation is about 710:1. A reasonable assumption may be that the incursion of fresh water, evidenced by the clastic beds, into the somewhat concentrated waters of a basin temporarily changed the pH of the solutions and caused rapid deposition of manganese oxide. As conditions returned to normal, precipitation of manganese would have again been inhibited.

The manganese oxide beds, composed of an intimate mixture of very fine-grained hematite and cryptomelane, are dark gray to dull black on the outcrop and show an obscure banding, at least part of which is thought to represent bedding. The bedding (?) surfaces are undulatory and the top of the bed at places shows forms similar to those caused by interference ripple marks. A minor part of the ore is vuggy and in one bed is locally nodular, but most of it is dense and all of it is hard.

Dorr estimated 4,420,000 tons of measured ore, 11,750,000 tons of indicated ore and 17,500,000 tons of inferred ore, with an average content of about 45.6 percent manganese and 11.1 percent of iron in Morro do Urucum. Additional large tonnages, in thinner beds, occur nearby. Small amounts of phosphorus (0.33 P maximum) are present in much of the ore. Sampling in the limited workings shows that phosphorus decreases somewhat with distance away from the outcrop.

Although very little development work has been done in the district, about 60,000 tons have been shipped, all from the thick lower bed which has been penetrated to about 30 meters in from the outcrop. To export large tonnages would require a considerable capital investment in barges and tugs to transport the ore some 1,700 miles, via the Paraguay River to the Plate Estuary for transhipment to world markets. This, together with the relatively high iron content of the ores, has so far retarded development of the district.

Morro do Urucum is one of several similar but little known mesas, distributed over an area of at least 1,200 square kilometers in western Brazil and eastern Bolivia. The rocks at Morro do Urucum form a gently dipping, somewhat irregular basin; the other mesas, though unknown in detail, also appear to be structurally simple.

DEPOSITS FORMED BY WEATHERING PROCESSES.

With the exception of the Urucum deposits, all manganese deposits in Brazil that can be considered potential ore sources at this time have undergone (a greater or lesser amount of) concentration through weathering processes. It should be emphasized that in many parts of Brazil, weathering is so active that rocks exposed in adits several hundred feet below the surface are apparently as altered as those near the surface. However, some rocks are very resistant even

to this intense weathering; among them are certain gneisses and quartzites, compact hematite, some manganese silicates, and limestones and dolomites.

Manganese Deposits Enclosed in Itabirite (Metamorphosed Iron Formation).

Many of the manganese deposits of central Minas Gerais are in itabirite, a laminated quartz-hematite schist in which the quartz and hematite are in individual lenses 0.1 to 3 centimeters thick and many meters long and in which the quartz is crystalline and granular. The writers consider this rock to have been derived from laminated chemical sediments, similar to those at Morro do Urucum, by regional metamorphism.

Wigg and Burnier.—The most widely discussed manganese deposits of this type and probably the ones with the greatest total production are the Wigg and Burnier mines near São Julião (formerly Miguel Burnier) (Fig. 2). Mining started here in 1894 and continued steadily until the 1930's. The shipping grade was originally about 50 percent manganese, but later declined to about 40 percent.

The São Julião mines were described during their heyday by Scott (2), who called the Burnier "a residual deposit from which the other elements have been leached." The ore seems to have been limited to a well-defined bed that "ranges widely in thickness," but, as indicated by Scott's sections, seems to have averaged about 3 meters thick. The ore was overlain by itabirite or the soft crumbly pure hematite known as jacutinga, and was underlain by earthy iron and manganese oxides. Above the itabirite is a gray limestone, and below the earthy material a white limestone.

Scott thought that the limestones were significant in the genesis of the manganese deposits, and he states that the manganese was probably deposited in the form of the carbonate. Derby (2, discussion) agreed with Scott, and stated further that he thought iron in the iron formation itself may well have been carbonate. Scott published analyses of the limestones that show a manganous oxide content of 1.45 percent for the white limestone and 1.40 percent for the gray limestone. He considered this amount of manganese to be significant and, because the ores were soft, porous, and vuggy, he concluded that the deposits were derived from manganese carbonates. He did not see the original material from which the ores came. Disagreement with Scott has been expressed by Harder and Chamberlin (7), who concluded that the ores were originally sediments, deposited as manganese oxides, and altered subsequently by metamorphism. The reasons for this conclusion are not clear. Miller and Singewald (10) believe that the manganese ores are not at definite horizons, but are coextensive with limestone lenses and that "it seems that they (the manganese deposits) represent replacements of the limestone lenses."

The origin of the deposits must remain in doubt until more definite information concerning their character at depth is obtained. It is of interest that, judging from Scott's original description, the manganese was more closely associated with itabirite than with any other rock.

Lagôa Grande.—The deposits at Lagôa Grande, from which about 70,000 tons of ore ranging from 40 to 46 percent manganese has been produced in re-

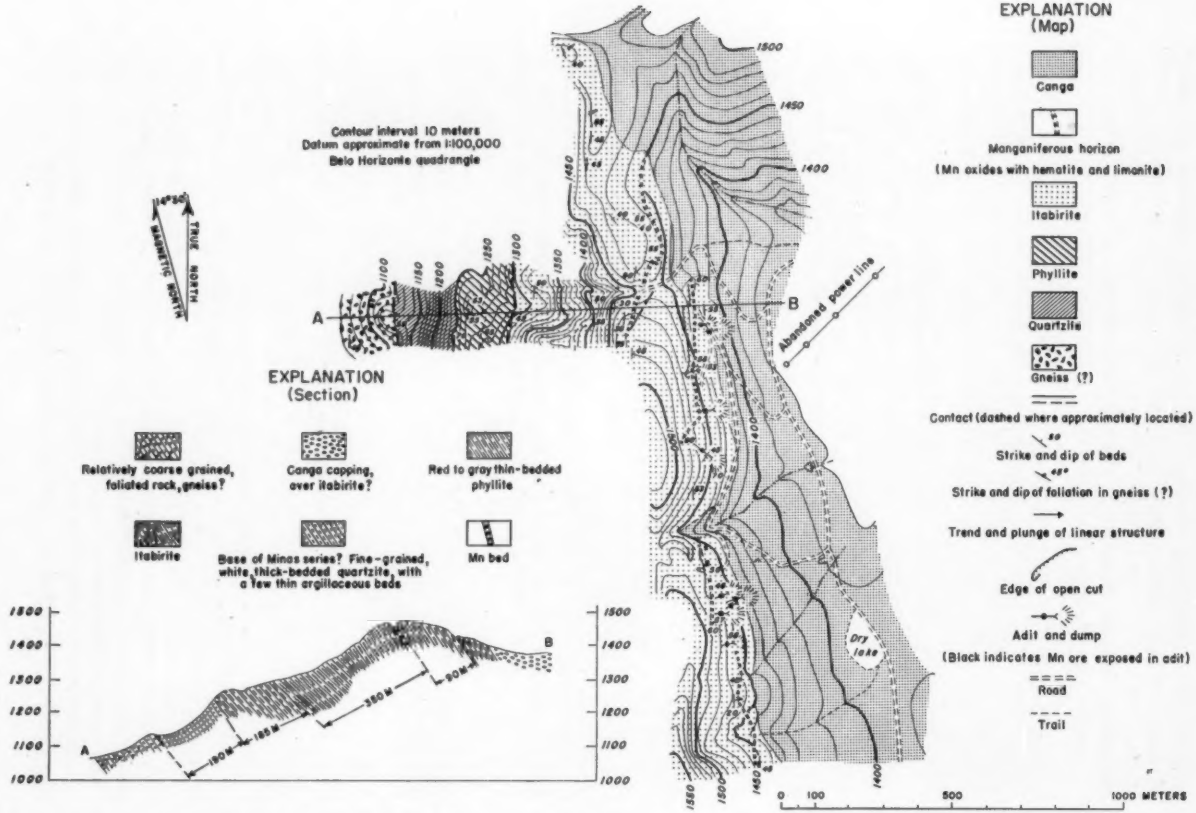


FIG. 3. Geologic map of part of the Lagôa Grande manganese area, Minas Gerais, Brazil.

FIG. 3a. Cross section of part of the Lagôa Grande manganese area, Minas Gerais, Brazil.

cent years, are situated near the crest of the Serra da Moeda, south of Belo Horizonte (Fig. 2). Part of the area that has been actively explored and mined is shown on Figures 3 and 3a. As seen in the cross section, two principal manganiferous horizons are present in the upper part of the itabirite. In both plan and section they are conformable with the enclosing non-manganiferous part of the formation. The deposits are lenticular, range from a meter or less to about 10 meters in thickness, and have exposed lengths of as much as 550 meters. At least three lenses occupy about the same horizon within the mapped area, and similar ones are known both to the north and to the south along the ridge, which extends for about 50 kilometers. Thin, low-grade manganiferous lenses exposed in shallow prospect trenches at the northwest corner of the mapped area are stratigraphically lower in the section and indicate that the manganese is not confined exclusively to the principal horizons.

The mineralogy of the Lagôa Grande deposits appears to be simple, though careful laboratory determinations have not been completed. As far as is known the ore consists of pyrolusite and psilomelane, with more or less hematite, surficial supergene limonite, and magnetite similar to that found in laterites. In many places cores and nodules of good ore are separated from the iron formation by gradational zones of soft limonite and clay with lesser amounts of manganese oxides in veinlets and pellets. Part of the ore is vuggy and shows colliform structures in which the "bunches of grapes" point vertically downward. This feature is obviously related to the present surface because the enclosing rocks have moderate dips. The manganese has evidently been reworked since its original deposition. Quartz in which cleavage or parting planes are conspicuously well developed seems to be characteristic of the ores from Lagôa Grande as well as of other deposits within the iron-formation, but the quantity is small in relation to the volume of the ores, and any genetic significance it may have is not evident. This quartz may be a minor consequence of the same process that concentrated the manganese.

The ores vary widely in tenor, depending upon the degree to which the manganese originally present in the iron-formation has been concentrated by supergene processes. Analyses of two samples, given in Table 1, illustrate this.

TABLE 1.

ANALYSES OF MANGANESE ORES FROM LAGÔA GRANDE*

	Sample 1 percent	Sample 2 percent
Mn	39.2	20.3
Fe	15.1	32.7
SiO_2	0.65	0.80

*Analyses made in the Departamento Nacional da Produção Mineral laboratory, Belo Horizonte.

Sample 1 represents six meters of material from the lower horizon which can be sorted by hand to give a good product. Sample 2 represents about the same amount of material from three narrower zones separated by itabirite, exposed in one of the prospect trenches at the northwest corner of the area. The combined manganese and iron content of the ore is more or less constant, and within

manganese area, Minas Gerais, Brazil.
Minas Gerais, Brazil.

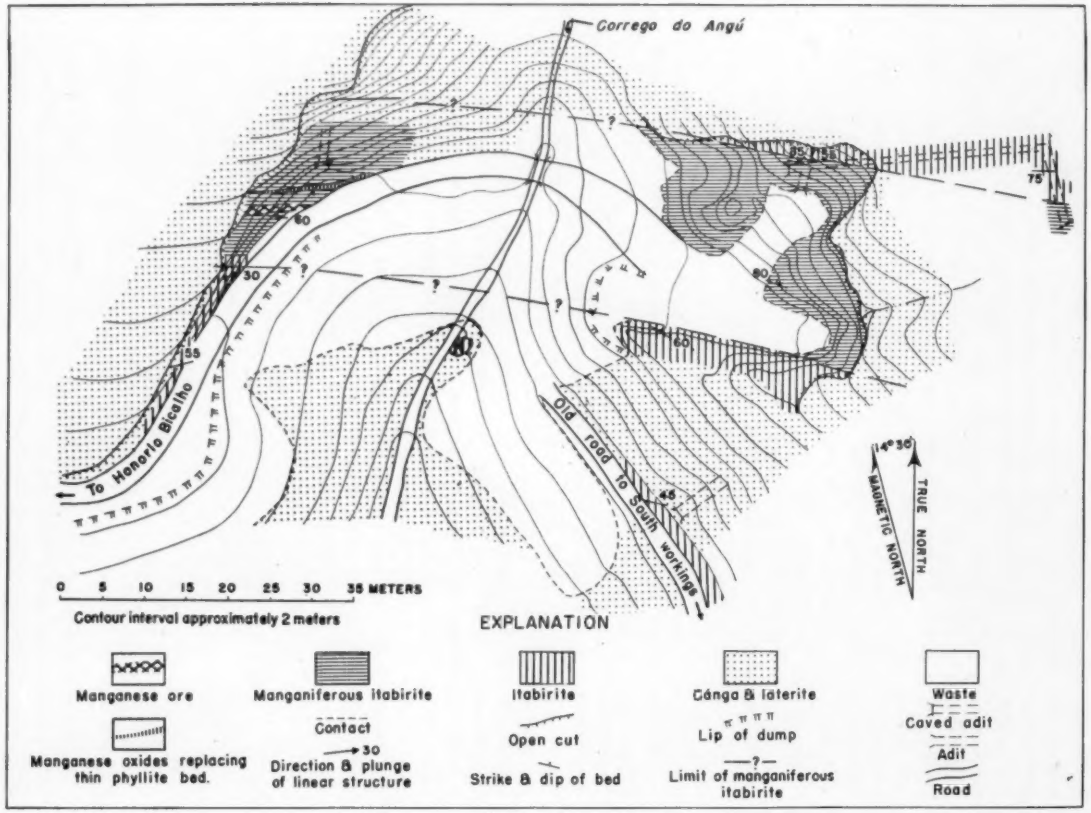


FIG. 4. Sketch map of Capitão do Mato mine, Minas Gerais, Brazil.

certain limits the grade of the product can be controlled by sorting. The present operators consider that the most economical range is 40 to 42 percent of manganese.

Capitão do Mato.—A smaller deposit, similar to those at Lagôa Grande, is the Capitão do Mato, about 9 kilometers to the northeast (Fig. 2). Little is known of the geology of the property except that it is in a zone of itabirite trending east-southeast, with moderate to steep north dips which in places are overturned to the south (Fig. 4). Manganese oxides similar to those at Lagôa Grande are distributed throughout a zone about 22 meters wide. The length of the zone exposed on the surface is about 75 meters, and an adit indicates that it continues at least 20 meters to the east. A thin zone at the western edge of the exposed area is composed of what appears to be high-grade ore; the rest is material with a variable iron content that must be sorted. The grade of the ore as shipped is said to average about 38 percent manganese. A 1-meter bed of phyllite, exposed near the western edge of the mapped area, has been partly replaced by manganese oxides to form a soft, black, sooty wad. An abandoned open-cut about 75 meters southeast from the principal workings indicates the presence of a second manganiferous horizon of less value. Most of the surrounding area is covered with a heavy mantle of canga, loose canga float, and unconsolidated itabirite rubble which effectively conceals the underlying rocks.

Origin of Deposits in Itabirite.—More than 50 deposits of manganese oxides enclosed in itabirite are described in the literature, and of these a considerable number have been examined by the authors. Many occur in the vicinity of limestone or dolomite, but at least as many do not. In no deposit have appreciable quantities of manganese oxides been seen in intimate association with carbonate rocks. It appears, therefore, that this spatial relationship is fortuitous.

No manganese carbonates, silicates, or sulfides have been observed by the present authors either in the field or under the microscope, and none have been reported in the literature. If these materials were ever present they have been effectively obliterated by weathering or other processes. It is considered likely that, had silicates been the source minerals, residues or traces of them would have been found somewhere in the extensive workings, even though these are relatively shallow. As remnants or relict structures, especially of spessartite garnet, are common in the ores of all the Brazilian deposits known definitely to have had silicate in the protore, their absence in the deposits enclosed in itabirite implies that the manganese silicates were never present here. The oxides conceivably could have formed from carbonates or sulfides, however, as these minerals are destroyed more readily by weathering. The former presence of manganese minerals other than the oxides cannot therefore be regarded as disproved.

The authors believe that the origin of the ore may be reasonably explained by the deposition, contemporaneously with the silica and iron oxides of the itabirite, of primary manganese oxides that were later concentrated by the removal of iron and silica during weathering. A 30-centimeter bed of itabirite exposed near Congonhas do Campo, which may be an example of this type of protore, has the following composition, by percent: Fe, 57.6; Mn, 3.36; SiO_2, 4.3; P, 0.02; H_2O, 1.94. Surface material overlying this bed shows an increase

of manganese to 8.98 percent and significant decreases in iron and silica. The mobility of iron under surface weathering conditions in Brazil is clearly demonstrated by the vast sheets of canga (limonite-cemented hematite conglomerate, locally almost pure limonite) that cover many tens of square kilometers in the area. The mobility of silica is equally evident, and was proved by Harder and Chamberlin (private report) at the Alegria property of the Brazilian Iron and Steel Co., where residual enrichment of itabirite occurred on a large scale.

The usual manganese content of itabirite is extremely low and when manganese is found, it seems to be restricted to horizons of limited thickness. This is true not only of the unconcentrated material cited above, but also of the concentrated ore of the Lagôa Grande type. Possibly the original sparse manganese minerals of the particular horizon being enriched served as nuclei on which were redeposited the manganese dissolved by downward-moving supergene solutions. Manganese not so deposited moved out through the itabirite with dissolved iron and was precipitated as manganiferous canga. Overlying the manganese beds and for short distances down slope, the canga commonly contains enough manganese to stain it black.

The foregoing hypothesis of origin would make the nature of the original iron formation in Minas Gerais similar to that of the rocks now exposed at Urucum. De Paiva, quoting Gerth (21), Almeida (29), and O. Barbosa (unpublished report on geology of Congonhas do Campo area, Minas Gerais) have considered such a hypothesis. Tyler's unsuccessful search for heavy minerals of clastic origin in itabirite led him to the conclusion that itabirite was derived from chemical sediments (31). It is significant that neither the Paleozoic age of the formations at Urucum nor the Precambrian age of the rocks of Minas Gerais can be considered as proved.

If a similarity of depositional environments existed, there would remain to be explained the relatively high manganese-iron ratio of Urucum ores compared to that of the itabirite protores of Minas Gerais. The presence of clastic beds associated with the manganese ores of Urucum, not found in the itabirite manganese ores of Minas Gerais, may provide a clue. In the Band'Alta formation of Urucum, a change of sedimentary environment took place at the time of deposition of the manganese oxides; no clastic sediments are found in the itabirite near the manganese in Minas Gerais, and no such change in depositional environment is indicated. At Urucum the change is thought to have inhibited precipitation of silica and of iron to some extent, but in Minas Gerais both these oxides were deposited with the manganese. The clearcut localization of the manganese in certain horizons, especially at Urucum and to a lesser degree in Minas Gerais, indicates that some effective process of separation was at work.

Manganese Deposits Derived by Alteration of Manganese Silicate-Carbonate-Sulfide Bodies.

Deposits of manganese oxides derived from the near-surface alteration of manganese silicate-carbonate-sulfide (?) rocks are known in many places in Brazil, though few of them so far have proved to be of commercial value over

a period of more than a few years. The silicate rocks, unless carbonates or other easily altered minerals are present, as at Morro da Mina, are likely to be resistant to weathering, and the resulting oxide deposits to be shallow.

Morro da Mina.—Probably the most widely known and certainly the most productive manganese deposit of Brazil is that at Morro da Mina, near Lafaiete

FIG. 5. Camera lucida sketch of polished section of protore from the Lafaiete district, Minas Gerais, Brazil.

(formerly Queluz), Minas Gerais (Fig. 2). It is in a complex of metamorphosed sedimentary rocks, extrusive basic rocks, and granitic gneisses of unknown origin which have been intruded by extensive masses of postmetamorphic, intermediate to silicic, igneous rocks. The earlier workers (Derby, Chamberlin, and others) consider this complex to be "Archean," and hence older than the Minas series in which the itabirite occurs. Guimarães, O. Barbosa, and many other present workers believe that the complex is essentially contemporaneous with the Minas series. The recent discovery of thin itabirite lenses a short distance northwest along strike substantiates their opinion.

The Lafaiete deposits were described years ago by Derby (3, 6), and his descriptions are good today. He considered the ore to be a superficial concentration of manganese oxides derived by weathering from easily altered manganese carbonates and somewhat more resistant silicates. To these minerals should now be added the manganese sulfide, alabandite, which is present in appreciable amounts in some of the unaltered carbonate-silicate rocks, or protore. The protore is well exposed in several places underground and in the open cuts. No complete collection of the protores has been made and only a few specimens were available for microscopic study. The material at hand consists of spessartite garnet, rhodonite, tiny crystals of an orange-yellow mineral that could not be determined with certainty, rhodochrosite, and alabandite (Fig. 5). Guimarães mentions the presence of neotocite (17). All stages of alteration, from the original silicate-carbonate-sulfide rock to pure manganese oxide, may be seen. At the bottoms of the ore shoots the ore extends downward along joints and fracture planes into blackened, but only slightly altered, rock (17).

The origin of the protore at Lafaiete has aroused considerable discussion in the past. Miller and Singewald (10) thought the material was a dynamically metamorphosed sediment. Hussak (4) and Guimarães (11) both favor the theory of contact metamorphism of impure manganiferous sediments. Guimarães also believes that some of the oxide now being mined is syngenetic.

The presence of considerable quantities of alabandite in the deeper protores might support the contact-metamorphic theory, as it would be a most unusual mineral to form by regional metamorphism. Alabandite is, however, usually considered to be a hydrothermal mineral (Hewett and Rove, 14), and its presence raises the question of what proportion of the protore may be of hydrothermal rather than contact metamorphic origin. Rhodonite and rhodochrosite both may be of hydrothermal origin and such an origin is usually assigned to neotocite. Manganese deposition may, therefore, have started under contact metamorphic conditions (spessartite) and continued into a hydrothermal stage, and much or all of the manganese may be epigenetic, introduced from an igneous source, rather than syngenetic, derived from the original sediments.

Alabandite readily oxidizes under weathering conditions, releasing sulfurous and sulfuric acid. These acids in turn attack the other manganiferous minerals, particularly rhodochrosite, in the protore leaving manganese oxide as an end product of the reaction. Thus, the presence of alabandite and rhodochrosite was undoubtedly an important factor in the formation of commercial ores, and the wide variations in depth and completeness of oxidation from one deposit of

this type to another may depend to a considerable extent upon the relative abundance of these minerals in the protore.

Saúde.—The Saúde manganese property is in central Minas Gerais, 60 kilometers southeast of the famous hematite deposits at Itabira (Fig. 2). When visited during July 1948, the mine was said to be producing about 40 tons a day. The ore, which averaged about 42 percent manganese after sorting, was being sent to Europe. The mine area has been described by Guimarães and Coelho (private report), who state that the country rock is phyllitic and schistose quartzite thought to belong to the Minas series. One small outcrop of itabirite and several large outcrops of skarn were seen several hundred meters from the mine. The deposits are lenticular or tabular and form impressive black outcrops which stand well above the country rocks. Much silicate rock is encountered at shallow depth, and a great deal of hand sorting is required. Unaltered manganese silicate is exposed in a small stream bed just below the present workings. Very few grains of carbonates were seen in the rock, but one specimen showed a few tiny grains of alabandite. All the ore examined, other than the reworked material in the soil, contains small remnants of garnet or rhodonite or sufficient clay to show the outlines of garnet crystals.

It is questionable whether mining of the known oxide bodies will extend much below the present shallow workings. The manganese oxides are in seams and joints, and in pockets, boulders, and small pellets or nodules in the soil (granzon). From visual inspection some of the boulders and pellets appear to to be high grade and amenable to washing or other simple recovery processes.

Most of the work to date has been concentrated on one outcrop. The ore is broken and all must be carefully hand sorted to bring it up to grade. The silicates are rejected, though they are kept in a stockpile for possible treatment later.

Portão.—About 8 kilometers southwest of the Saúde workings is the Portão deposit, now abandoned. The ore is in weathered manganese silicate rock, similar to that at Saúde, and is enclosed in phyllitic and schistose sandy beds. In one of the several small open-cuts the mineralized zone appears to stand nearly vertical, though the wall rocks dip about 60° SE. The ore is exposed for a vertical height of about 10 meters in another small open-cut, where it consists of small nodules of manganese oxide in a clayey matrix. The ore material also contains small amounts of manganese silicates in which spessartite is conspicuous. The other cuts are slumped and overgrown, and furnished no additional information. The general alinement of the manganiferous bodies is nearly due north, and they possibly represent a continuation of the line of ore bodies at Saúde, which they strongly resemble. Much of the region is covered with dense vegetation and has not been thoroughly explored.

Amapá.—About 150 kilometers west-northwest of the town of Macapá, in the Federal Territory of Amapá, is the little-known and thickly wooded area of the Serra do Navio (32) (Fig. 1). Manganese oxides were first noted along the Amapari River in 1941, and a small amount of development work has been done during the past three years. The region is one of deep tropical weathering, though at low water comparatively fresh rocks are exposed in the river bed.

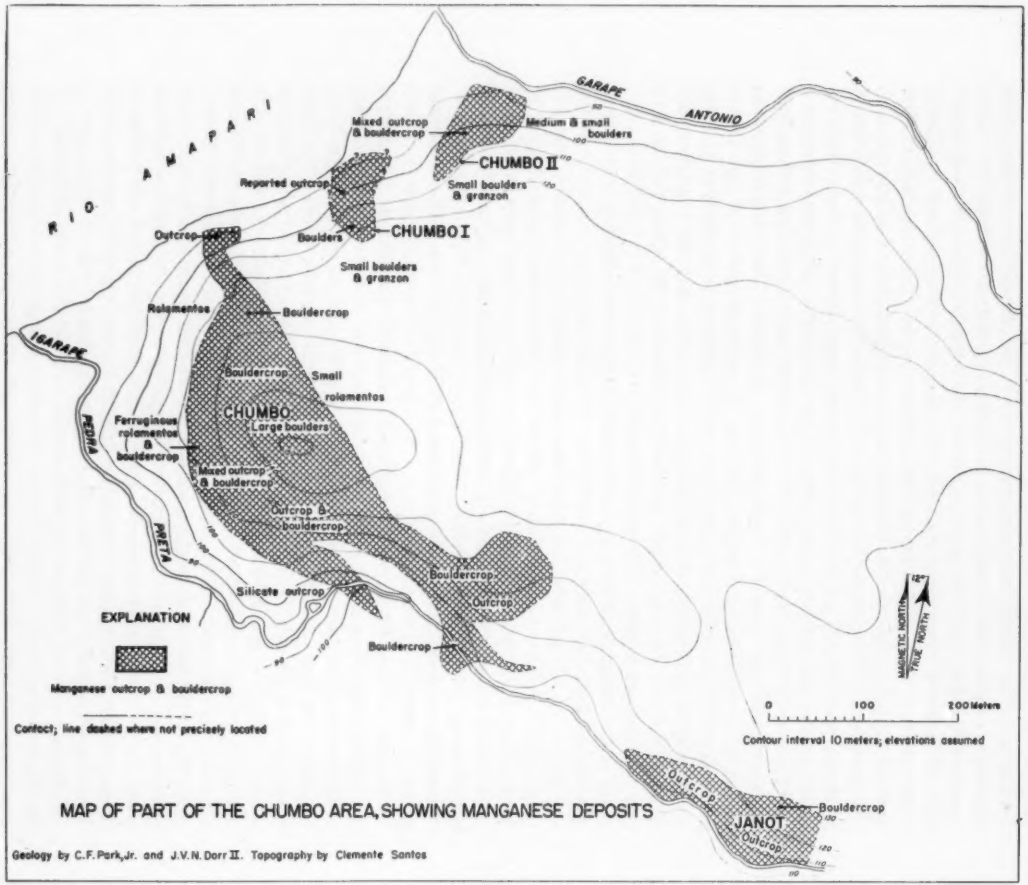

RIO AMAPARI
GARAPE
ANTONIO
Mixed outcrop & boulder crop
Medium & small boulders
CHUMBO II
Small boulders & granzon
Reported outcrop
Outcrop
Boulders
CHUMBO I
Small boulders & granzon
Rolamentos
Boulder crop
IGARAPE
Boulder crop
Small rolamentos
CHUMBO
Large boulders
PEDRA
Ferruginous rolamentos & boulder crop
Mixed outcrop & boulder crop
Outcrop & boulder crop
PRETA
Boulder crop
Outcrop
Silicate outcrop
EXPLANATION
Manganese outcrop & boulder crop
Contact; line dashed where not precisely located
MAGNETIC NORTH
TRUE NORTH
0 100 200 Meters
Contour interval 10 meters; elevations assumed
Outcrop
Boulder crop
JANOT
Outcrop
MAP OF PART OF THE CHUMBO AREA, SHOWING MANGANESE DEPOSITS
Geology by C.F. Park, Jr. and J.V.N. Dorr II. Topography by Clemente Santos

FIG. 6.

These rocks are thought to be of Precambrian age, and to be part of the ancient crystalline shield that forms the Guiana highlands. They apparently consist dominantly of granitic gneisses, quartzites, and amphibolites. Iron formation with ore bodies of moderate size is known to exist about 100 kilometers to the south-southeast. One dike, in the river bed at the main camp, consists largely of roughly alined crystals of hornblende and analcite with small cores of albite. This dike is unmetamorphosed and unaltered, and indicates postmetamorphic intrusion of comparatively recent (Tertiary?) geologic time.

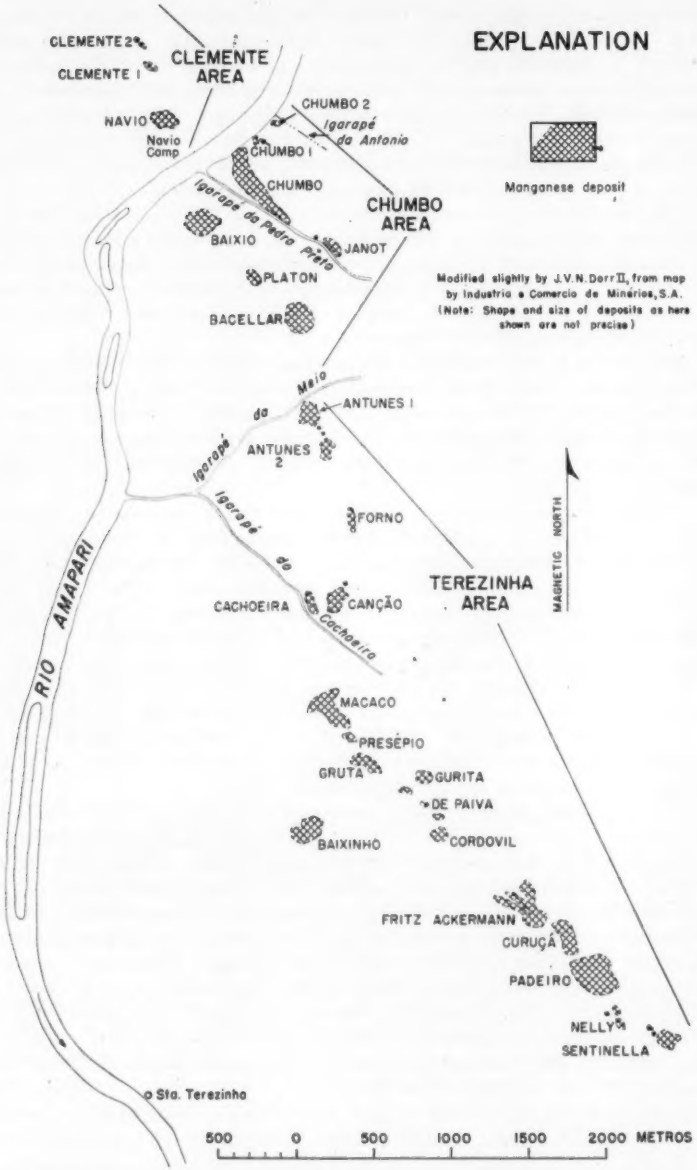
The first discovery of manganese in the region was along the river, but later prospecting has enlarged the area in which such deposits are known. Individual deposits, such as the Chumbo, seem to be in moderately dipping beds (Fig. 6). Other deposits more nearly resemble lenses or possibly crosscutting tabular bodies. About 28 separate manganese deposits have been found to date. Their distribution is shown in Figure 7.

Exploration is still insufficient to permit adequate evaluation and appraisal of the deposits. Dorr, Park, and de Paiva (32) have estimated tonnages as follows: visible, 585,000; probable, 2,700,000; possible, 4,100,000. Grade of visible ore is about 50 percent manganese; data are inadequate to predict the grade of the other classifications, although much of the material will be of good quality.

Fig. 6.

The outcrops consist of cryptomelane with minor amounts of soft pyrolusite (?). Spots of white clay (halloysite) and gibbsite are locally abundant. Some of the material near the footwall of a few of the deposits has a granular texture suggestive of the decomposition of garnet rock. The garnet rock, known as gondite, consists largely of spessartite and may be observed in the valleys of two small streams, where it is covered by a thin coating of manganese oxide. Locally the spessartite crystals are very closely packed and little space is left for other minerals; in other parts of the rock the garnets are widely spaced in interstitial manganese oxide. Although all the rock is altered and it is impossible to be sure what minerals other than spessartite may be present at depth, it seems very probable that manganese carbonate, other manganese silicates, and manganese sulfide will be found.

The enrichment of the rocks at Amapá has been discussed by Leinz (30) and by Dorr, Park, and de Paiva (32). Leinz gives excellent illustrations of the altered and partially altered garnet rock and describes the alteration process in detail. He states that the small whitish spots found in some of the ore are high-alumina clays and result from the decomposition of spessartite. In thin sections, the shapes of the garnets are easily recognized; manganese oxide has apparently moved out from the centers of the crytals. It may have replaced the unknown material of the interstices or may have moved on to be deposited elsewhere if the unknown material consisted of primary manganese oxide or (more probably) of manganiferous minerals more easily oxidized than spessartite. Small amounts of manganese remain in the pseudomorphs; many of these pseudomorphs are unusual in that the manganese is arranged in radiating lines of inclusions in the clay. Some of these inclusions are arranged in the form of crosses, as if alined along crystallographic directions by the expulsion of ma-



MAP SHOWING RELATIVE POSITIONS OF MANGANESE DEPOSITS, SERRA DO NAVIO DISTRICT

FIG. 7.

terial during alteration of the garnets (Fig. 8). Transitions between the small white clay spots and slightly altered garnet crystals have been seen; the conclusion is inescapable that the manganese oxide of the ore has originated in part from the decomposition of spessartite. Whether the mineral spessartite is a significant source of manganese oxide will not be known until much more exploration has been done.

The manganese ores seem to be of good grade, for more than half the assays of 210 samples collected by competent geologists show more than 50 percent of manganese and fewer than 30 percent show less than 45 percent of manganese. The incomplete removal of the clay minerals lowers the grade of some of the material. Samples of the ore have shown the presence of arsenic in amounts as high as 0.24 percent maximum. Phosphorus is negligible.

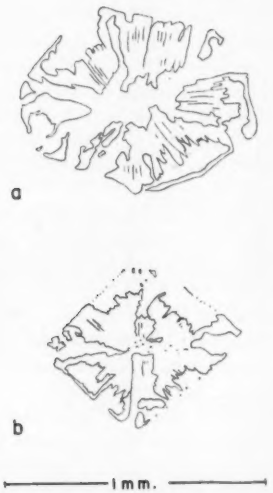


FIG. 8. Camera lucida sketches of two altered garnet crystals from Serra do Navio, Territory of Amapá. Notice the arrangement of the manganese oxide particles in the form of a cross in (b). Both drawings are of halloysite in a matrix of manganese oxides.

Deposits Formed by Alteration of Other Manganese-bearing Rocks.

Manganese oxide deposits may be concentrated as a result of the weathering of any rock that contains a few percent of manganese. Such deposits have been reported from several places in Brazil, though most of them are small and of little economic value.

Pecora (2) has described a manganese oxide deposit of this class from the State of Goiaz, near São José do Tocantins. Manganese oxide deposits that contain appreciable amounts of nickel and cobalt are intimately associated with

deposits of nickel silicate, and result from the long-continued weathering of pyroxenitic peridotite. The manganese is found in three forms: (1) a capping on near-surface, garnieritized, weathered pyroxene; (2) thin, soft, discontinuous veinlets in near-surface, purplish and greenish clays; and (3) as concretionary "pebbles" embedded in loose, reddish, ferruginous soil within a meter of the surface (granzon). None of the material is of sufficiently high grade to permit mining at present although analyses of the second type show as high as 4.3 percent of cobalt.

Deposits of Manganese Oxides Transported and Redeposited in Barren Rock.

Manganese oxides have been known for many years in the State of Bahia, though they have proved to be of little economic value. Two districts in the Serra de Jacobina, Jacobina and Bonfim, have recently been described in considerable detail by Capper de Souza (24), who considers that the ores, although somewhat different genetically, are in both places the result of superficial concentration. The Jacobina deposits fill minor fissures in schists and quartzites. These fissures are thought to be parallel to one of the major structural trends of the region, and where breccias are formed, the fractures around the fragments are filled with manganese oxides. The nature of the original mineral is unknown, though the deposits appear to be formed as the result of decomposition of material in the underlying bedrock.

The Bonfim deposits were worked during World War I. They are a shallow blanket-type of residual material that does not occupy veins, as do the deposits at Jacobina. The underlying rock is the gneissic and schistose basement complex of Precambrian age.

Other deposits of manganese oxides have been operated near the village of Santo Antonio de Jesús, about 25 kilometers west of Nazaré, in Bahia. This ore is also said to be a near-surface concentration which resulted from the weathering of the Precambrian basement rocks.

At the Timbopeba and many other mines in central Minas Gerais, manganese oxides have been recovered from thin fractures and irregular replacement bodies in phyllites and sericitic quartzites. The freshest bedrock seen contains no manganese, and it is thought that the ore minerals were introduced from outside sources.

The soils overlying and near some of the manganese deposits contain pellets and small boulders of manganese oxides identical with those which in Cuba are termed granzon. These oxide pellets resemble the material found in laterites, and are thought to form in much the same manner. Many of them have concentric structures, and the manganese in them has been transported at least short distances in solutions. The deposits are worked in conjunction with other routine mining operations, though few would be of economic value if mined alone. The total production from this type of deposit is small.

SUMMARY AND CONCLUSIONS.

The principal Brazilian manganese deposits fall into three types, which may conveniently be summarized in ascending order of complexity according to the

geological processes that have affected them. The least altered is the Urucum type, a primary sediment still preserved essentially as deposited. Manganese ores enclosed in itabirite represent an intermediate type that underwent regional metamorphism and subsequent surficial concentration during the present erosion cycle. The ultimate source of the manganese of the Queluz or Morro da Mina type is obscure because of the complicated geologic history of the deposits. The rocks of this type have undergone both regional and contact metamorphism. It is probable that manganese derived from igneous sources forms at least part of the silicate-carbonate-sulfide protore from which the present ore bodies were derived by weathering processes.

The most productive deposits have been of the Queluz type, and the recent discovery of similar deposits in Amapá seems to assure that this type will continue to be important in the future. Deposits associated with itabirite have furnished considerable ore in the past and will no doubt continue to supply moderate tonnages particularly of medium- to low-grade ore, for many years to come. The Urucum ores, although they have hardly been touched as yet, seem destined to be an important source of manganese in the future. Deposits of other types—formed by concentrations of manganese oxides in sterile or only slightly manganiferous rocks—are comparatively small.

Brazil is fortunate in having two potentially large sources of ore so located that they are, from a cost viewpoint, as close to export as to domestic markets, as well as one deposit of export grade located on a main railway. To care for domestic needs, there are many deposits unsuited for export ore but advantageously located for domestic markets. The aggregate reserves available in such deposits seem adequate for many decades to come.

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Geologic Division, Foreign Section,
Washington 25, D. C.
AND
Departamento Nacional da Producão Mineral,
Rio de Janeiro, Brazil,
July 27, 1950.

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PETROGRAPHY OF AMERICAN LIGNITES.

B. C. PARKS.

ABSTRACT.

The extensive deposits of low-rank coal in the United States are receiving more than usual attention as a result of declining reserves of competitively more favorable coals and the development of important nonfuel uses of coal. Use of domestic lignite for solvent extraction of montan wax to replace foreign supply cut off from American industry is an example.

This paper describes briefly occurrences of lignitic coals in the United States and includes discussion of terminology, petrographic composition, coalification, and rank classification of these coals.

Certain tests are described and data presented showing results of petrographic investigation of the source of wax and resin in lignite. Purpose of the investigation was to determine the components in lignite contributing to the solvent extraction products, and the phyteral source of "waxy," "resinous," and "asphaltic" elements in the extracts.

Certain varieties of attrital lignite proved to be the most important source material of waxy solvent extracts. "Pure" attrital lignite of known high solvent yield was broken down by a method of chemical maceration which removed humic matter and freed various ingredients of the attritus, mostly yellow translucent matter. Phyteral components in the residue were spores, pollen, particles of lump-type resin, round, light and dark resinous bodies, dark "resinous" rodlets, remains of petioles and cuticular matter.

A microscope hot stage was used to observe the effect of heat on these various ingredients and their solvent products. Information resulted which indicated that, for attrital lignites tested, the wax in solvent extracts is derived mainly from cuticular remains, resin from lump-type resin and round resinous bodies, and asphaltic material probably from dark "resinous" bodies. The discovery of wax associated with cuticular remains is in keeping with the known fact that in living plants wax is found exclusively in cuticular coverings of leaves, petioles, and reproductive organs, and in suberin. Origin of attrital and xyloid lignites is discussed.

INTRODUCTION.

INFORMATION concerning the nature and properties of the higher-rank coals in the United States—that is to say, higher in rank than lignite—is available in relative abundance. Work in a number of laboratories where investigation of coal is the primary concern has resulted in the accumulation of considerable amount of analytical and test data. This information has been essential in systematically classifying and evaluating the bituminous and anthracitic coals. Lignite has not fared so well.

Coal scientists who consider the complete picture of metamorphic progression of coaly material from organic debris to meta-anthracite as a problem common to better knowledge of all kinds of coal, in a sense, may regret that scientific work in this country has been concentrated almost exclusively on the

bituminous coals. However, such approach to the study of coal was not accidental or result of poor planning. Extended scientific investigations in the field and laboratory are generally restricted to the natural resources of proved commercial value and wide demand. The tremendously important coal industry in this country, with few exceptions, has paid little attention to lignite, obviously because of its poor competitive quality as a fuel. But with declining reserves of the more desirable coals and development of interesting new uses of coal for nonfuel purposes, attention is now focusing on our large deposits of low-rank coal.

For example, recovery of an extractable product termed "montan wax" was the basis of a large mining and processing industry in the brown-coal areas of central Germany and in Czechoslovakia. Many useful applications were developed for montan wax, and it was distributed for commercial consumption on a world-wide scale before the German-controlled industry was disrupted as a result of World War II. The postwar status of the montan-wax industry in central Europe is not known with certainty.

Montan-wax requirements for industrial use in the United States before World War II were met by imports from Germany, which in the peak year totaled almost 12,500,000 pounds. But, owing to the shortage that has existed since 1940, industry was forced to use substitutes and, if general use of montan wax is reestablished in the United States, a dependable supply extracted from our domestic lignites seems essential.

With the intention of lending assistance in determining the possibilities of the American montan-wax industry, the Bureau of Mines in 1945 began a study of solvent extraction yields of domestic lignites. A paper summarizing the laboratory investigation of extractable waxes from American lignites was presented at a symposium of the Division of Gas and Fuel Chemistry, American Chemical Society, in Pittsburgh, May 9–10.[1] A complete report of the investigation, comprising a coördinated study of yields, chemical and physical tests of extracted products, and petrography of the lignites, will be published at an early date.[2] The paper presented here discusses certain significant geological and petrographical aspects of the lignites investigated.

LIGNITE PROVINCES IN THE UNITED STATES.

Coal of lignitic rank occurs in the United States in three widely separated regions, each quite large in areal extent. M. R. Campbell grouped the regional lignite deposits on the basis of the geographical and geological relationships into the Gulf, Northern Great Plains, and Pacific Coast provinces.[3] Geographical distribution of lignitic and subbituminous coals in the United States is shown in Figure 1.

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Gulf.—The Gulf province in the lower Mississippi Valley includes portions of Alabama, Mississippi, Tennessee, Arkansas, Louisiana, and Texas which lie in the physiographic division known as the Gulf Coastal plain. The coal deposits of economic importance in the Gulf province belong stratigraphically to the Wilcox group of nomarine sedimentary beds. These sediments, consisting of interbedded clay, sand, lignitic clay, and lignite, were deposited along an emerging coastal plain in the early Eocene epoch following withdrawal of the Midway sea from the Mississippi embayment. A large number of Wilcox lignite deposits are known from Alabama to Texas from outcrop exposures, wells, test holes, and mines. Coal mining has been confined to Texas and Arkansas, Texas accounting for nearly all of the 36 million tons mined in the

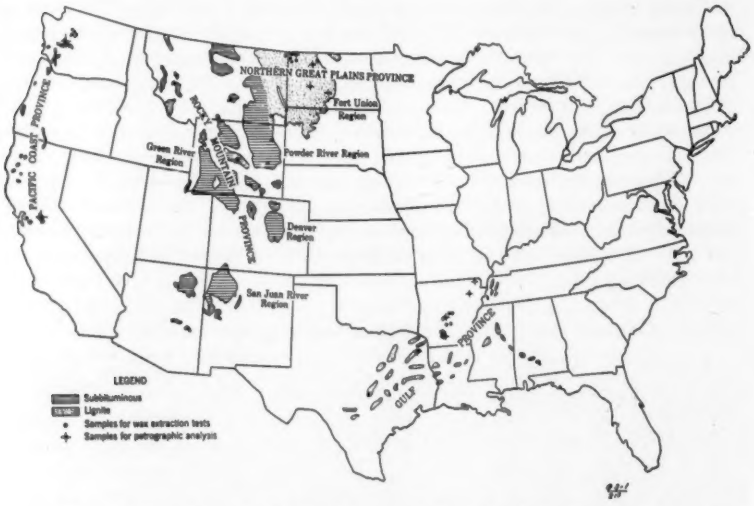

FIG. 1. Lignite and subbituminous coal deposits of the United States.

province. Typical Wilcox lignite deposits are 2 to 6 feet thick, irregular in outline, and of limited areal extent. In Texas and Louisiana beds up to 15 feet in thickness are known. Whereas the size of most of the individual deposits is relatively small, the number of lignite beds present in the several hundred feet of sediments constituting the Wilcox group probably is quite large.

Northern Great Plains.—This province includes the western half of North Dakota, eastern part of Montana, northeastern Wyoming, and northwestern South Dakota. The area containing lignitic coal in this province is referred to as the Fort Union region, named from the most important coal-bearing formation. The Fort Union formation in maximum thickness consists of about 1,500 feet of nonmarine shale, sandstone, and lignite. These terrestrial deposits were laid down during the Paleocene epoch of early Tertiary time.

Individual beds of lignite in the Fort Union formation are usually much thicker and more continuous laterally than are the lignite deposits of the Gulf province. The Fort Union formation has been estimated to contain over 600 billion tons of lignite. A limited amount of mining is carried on in North Dakota, Montana, and South Dakota. Over 2,500,000 tons of lignite was mined in North Dakota in 1947, or about 96 percent of total United States tonnage. Until recently the lignitic bearing Ludlow shale extending over most of the northwestern corner of South Dakota was assigned to the Lance formation and believed to be of Upper Cretaceous age.[4] The Ludlow deposits, which are the chief source of lignite mined in South Dakota, are now thought to represent the basal part of the Fort Union formation and, therefore, have been reassigned to the Paleocene epoch of Tertiary age.[5]

Pacific Coast.—The better-known lignite deposits of the Pacific Coast province are found in central and northern California, western Oregon, and western Washington. The best known deposits occur in Amador County, Calif., near Ione and Buena Vista. Several of the beds that have been prospected vary in thickness from 4 to 30 feet. The coal beds are associated with clay and sand strata, which make up the Ione formation. The coal deposits of the Ione formation in mode of occurrence probably are similar to those of the Gulf province. There is evidence that they are lenticular and discontinuous deposits rather than extensive blanketlike beds characteristic of the Northern Great Plains province. The deposits near Ione and Buena Vista in Amador County, Calif., are of unusual interest because they are being mined and processed for wax recovery.

TERMINOLOGY AND CLASSIFICATION OF LIGNITIC COALS.

Terminology.—The terms "lignite" and "brown coal" have been the most widely used for designating the lowest-rank coals. The name "lignite" is of French origin and first came into use in that country for referring to deposits of dark-brown, firmly consolidated, banded, low-rank coals of the type common in early Tertiary sedimentary strata. The French lignites can be considered prototype of coal of similar appearance occurring in other countries and designated lignite. In the United States virtually all the early Tertiary low-rank coals are referred to as lignite, and in most occurrences the coal closely resembles French lignite.

The term "brown coal" (Braunkohle in German) probably first came into use in middle Europe, where the extensive deposits of low-rank Tertiary coals have considerable economic importance. In general, the European brown coals are characteristically loosely consolidated, brown, and granular textured and commonly contain "woody" layers. In addition to widespread European usage, the name "brown coal" is also given to the thick deposits of low-rank coal in Australia which are quite similar in appearance to German brown coal. The central European brown coals have been the standard of comparison for visually classifying similar deposits all over the world.

[4] Wilmarth, M. Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, p. 1234, 1938.

[5] Dunbar, Carl O., Historical Geology, John Wiley & Sons, Inc., New York, p. 411, 1949.

A number of names has been given to lignitic coals in recognition of marked variation in visual physical characteristics. The following more or less descriptive names have had common usage and to some extent rather indiscriminately in coal literature: Woody lignite, xyloid lignite, brown coal, mature lignite, immature lignite, earthy lignite, young lignite, amorphous lignite, fibrous lignite, brown lignite, black lignite, and bituminous lignite. In Europe the terms braunkohle, moor coal, schwelkohle, papierkohle, pitch coal, and pyropissite have been used to designate varieties of lignitic coal. It is quite evident that, for the most part, these various loosely used names are superficially derived, and there is little scientific justification in continued use, although they may be to some extent convenient for field dscription of deposits.

Classification.—In the A.S.T.M. system of coal classification,[6] the term "lignite" is applied to coals having heating values less than 8,300 B.t.u. per pound on a moist, mineral-matter-free basis. By this system of classification, lignitic coals are separated into two groups—lignite and brown coal. Lignite is defined as a consolidated variety and brown coal, unconsolidated. Although lignite, by position and description in the classification chart, is indicated to be farther advanced in rank than brown coal, rank differentiation is not based on analytical evaluations. The reason for this undoubtedly is limited availability of analytical data pertaining to brown coal. Only two small deposits of brown coal are known with certainty in the United States; these occur in the State of Washington, but other minor deposits, such as the occurrence near Brandon, Vt., may represent brown coals of late Tertiary age.

If the terms "lignite" and "brown coal" are to be used restrictively for binomial grouping of lignitic coals, it would be preferable to establish the rank separations on the basis of a measurable physical characteristic, such as heating value, as well as on visual physical differences. Obviously this cannot be done effectively with the known American deposits which, with the minor exceptions noted, are of early Tertiary age and at approximately the same stage of coalification. Brown coal and lignite deposits, however, do occur in various other countries which collectively represent all epochs of the Tertiary and probably all levels of rank development for lignitic coals. Enough analyses on bed-moist basis are needed of various lignitic coals to determine best arbitrary limits for grouping brown coal and lignite by means of calorific values.

PETROGRAPHIC COMPOSITION OF LIGNITIC COALS.

Petrographic Components.—Consideration of petrographic composition seems advisable to classify lignitic coals properly. The marked visual variation in lignitic coal is due, in part at least, to physical composition.

In a similar manner to the bituminous coals, lignitic coals occur in banded and nonbanded types. The banded type contains a conspicuous component that is quite readily recognized to be of woody derivation. Nonbanded lignite is composed of microscopic ingredients of many kinds, which impart a grainy texture to the coal surface, broken by an occasional thin strand of anthraxylon

[6] American Society for Testing Materials, Standard Specifications for Classification of Coals by Rank (A.S.T.M. Designation: D388–38): A.S.T.M. Standards, pt. III A, Nonmetallic Materials, pp. 1–6, 1946.

or fusain. The color of nonbanded lignite is light-brown if the amount of yellow translucent material, such as spores and resin, is relatively high, but if there is little of this material and much humic matter the prevailing color is dark brown.

If a small block of brown coal or lignite is mounted on a glass slide and ground and polished until uniformly less than 10 microns thick, the section becomes translucent, except for constituents that are truly opaque, such as fusain. The thin slices of coal examined under the microscope with transmitted light reveal the physical structure and composition of the coal. Just as in bituminous coals, anthraxylon, attritus, and fusain can be quite readily recognized in lignitic coals.

Anthraxylon is the yellowish-red translucent component relatively simple in structure and essentially homogeneous in appearance. It occurs in coal in the shape of lenticles whose length is many times their thickness. Anthraxylon appears in thin sections as well-defined bands of homogeneous structure running across the section, which is cut normal to the bedding planes. It is derived principally from the woody and bark tissues which forms the supporting organs of vascular plants, such as the roots, trunks, stems, and branches. The cellular and fibrous structure of woody and bark tissues can clearly be seen in transverse or longitudinal cross section. Thus it is apparent that "woody" lignites are those composed predominantly of anthraxylon.

Attritus, the other major component, unlike anthraxylon is quite complex. It consists of many microscopically small ingredients, some of which are opaque in the thinnest section, but most varieties are translucent and colored. Attritus represents the residual remains of plant debris, finely divided by decay and chemical action, principally during the peat stage. Much of the attritus consists of remains of fibrous tissues reduced to extremely fine shreds and preserving little evidence of original structure. This orange translucent substance has been called translucent humic degradation matter. An important element of attritus is made up of decay-resistant protective coats of organs associated with reproduction of plants, such as spores, pollen, fruit, berries, and seeds. The cuticular coverings of leaves and petioles contribute to the attritus, which also often contains much resinous matter. Opaque attritus, a minor ingredient of most attritus, cannot be assigned to any definite organic category of the plant remains. It is visually granular or amorphous.

Fusain is the least-important component in lignitic coal. It is opaque in thin sections and easily recognized by its porous structure, indicative of woody origin. Pore spaces are generally mineralized. Fusain is never present in large enough quantity to influence the general surface appearance of lignitic coals.

Petrographic Varieties of Lignitic Coal.—The name "xyloid" has been combined with "lignite" to designate coals composed dominantly of woody plant remains.[7] This usually has been the case when dominance of the woody component in the coal was obvious by visual observation.

White and Thiessen called a variety of lignite from Ouachita County, Ark.,

[7] White, David, and Thiessen, Reinhardt, The origin of coal: U. S. Bur. Mines Bull. 38, p. 7, 1913.

TABLE 1

PETROGRAPHIC COMPOSITION AND EXTRACTION YIELDS OF CERTAIN AMERICAN LIGNITES OF ATTRITAL AND XYLOID TYPE

Item No.	Occurrence		Kind of sample	Percent petrographic composition				Yellow translucent attritus, percent[1]	Extraction yields	
	State	County		Anthraxylon	Translucent attritus	Opaque attritus	Fusain		Benzene	Benzene alcohol 80/20
									Percent, air-dry basis	
1	Arkansas	Hot Spring	Face[2]	8.1	91.6	0.3	—	2.2	11.1	16.4
2	Arkansas	Dallas	Layer[3]	7.8	90.7	1.5	—	1.1	8.9	13.6
3	California	Amador	Face[4]	10.3	89.1	.6	—	1.2	14.2	21.2
4	California	Amador	Layer[5]	9.6	89.1	1.3	—	1.9	16.8	21.3
5	California	Amador	Layer[6]	19.6	80.0	.4	—	.1	9.5	13.6
6	Arkansas	Poinsett	Face[7]	16.2	83.4	.4	—	.4	7.6	11.6
7	Arkansas	Ouachita	Layer[8]	21.1	78.0	.9	—	10.6	10.2	15.7
8	Arkansas	Ouachita	Face[7]	24.1	75.0	.9	—	4.5	6.7	10.2
9	Arkansas	Clay	Face[9]	30.3	68.6	.9	0.2	.7	2.5	5.1
10	Texas	Harrison	Face[10]	29.7	64.4	4.9	1.0	.1	1.8	3.9
11	Texas	Harrison	Face[10]	34.8	54.5	8.8	1.9	.1	2.0	4.2
12	North Dakota	Divide	Face[11]	56.2	33.4	3.8	6.6	—	1.3	2.8
13	North Dakota	Burleigh	Face[11]	63.0	31.0	5.0	1.0	—	1.2	2.8
14	North Dakota	Ward	Face[11]	61.0	27.0	9.0	3.0	—	1.3	2.7
15	North Dakota	Mercer	Face[11]	53.4	25.1	15.4	6.1	—	.6	2.3
16	Arkansas	Dallas	Layer[12]	100.0	—	—	—	—	.3	3.1

[1] The yellow translucent attritus represented by values in this column included those yellow ingredients easily discernible as to color, shape, and size at magnifications used (60×). The yellow attritus of particle size smaller than 30 microns was not included in these determinations.

[2] Light-brown attrital lignite—oily luster on scratched surface—resin particles visible to unaided eye.

[3] Light-brown attrital lignite relatively rich in cuticular matter.

[4] Mostly dark-brown attrital lignite with layers of light brown coal.

[5] Light-brown attrital lignite with relatively large amount of very finely divided yellow translucent attritus mostly minus 30 microns in size.

[6] Very dark brown attrital lignite consisting predominantly of reddish translucent humic degradation matter.

[7] Brown attrital lignite.

[8] Light-brown attrital lignite containing a relatively rich concentration of round, yellow bodies of particle size range from 30 to 80 microns in diameter.

[9] Brown attrital lignite unusually high in anthraxylon.

[10] Dark-brown lignite intermediate between attrital and xyloid types.

[11] Dark-brown lignite of xyloid type.

[12] Pure anthraxylon of distinct woody structure in thin sections and containing 21 percent by volume of dark red inclusions.

found to consist in large part of spores, "cannelloid lignite."[8] Later Thiessen, in an unpublished report, described coals similar in composition from the same area as "attrital lignite."

There is too little petrographic information concerning lignitic coal to delineate on the basis of quantitative measurements between xyloid and attrital lignitic coals. Available analyses of American lignite indicate that typical xyloid lignite such as occurs in North Dakota contains more than 50 percent anthraxylon. Typical attrital lignite from Arkansas and California contains less than 25 percent anthraxylon and more than 75 percent attritus (Table 1). It is recognized that the structure of individual deposits of lignite may be complex and that, within a single bed, benches of xyloid coal may occur inter-

[8] White, David, and Thiessen, Reinhardt, op. cit., p. 15.

layered with thick lenses of attrital coal. However, deposits of almost purely attrital lignite do occur, and there is commonly xyloid lignite, in which attrital layers are quite thin and intimately banded with the more prominent anthraxylon.

In Europe the importance of petrographic composition in determining the characteristic structure of the brown coals also has been recognized. "Papierkohle" and "leaf coal" are names applied to the fissile structured brown coal of the Moscow Basin, which is composed in large part of cuticular remains. The light-brown, earthy, highly resinous coal of Austria is called "pyropissite." "Moor" coal has been used to designate brown coal with no prominent anthraxylon or "woody" layers. Xylith is a petrographic variety composed almost wholly of anthraxylon. Pitch coal is a black variety mostly of xylith. The terms originally applied to the banded ingredients [9] of bituminous coals in England and on the continent have not been as extensively used in describing brown coal and lignite. Kreulen [10] suggests that the terms "vitrite" (vitrain), "durite" (durain), and "fusite" (fusain) can be aptly used in describing petrographic composition of brown coal. Vitrite and durite from Kreulen's description seem to be analogous to anthraxylon and attritus. Kreulen does not include for use in describing brown coal the term "clarite" (clarain), the most important component of banded bituminous coals in the Stopes system of nomenclature.

COALIFICATION AND RANK IN LIGNITIC COAL.

The rank level of lignitic coal is determined by measuring calorific value on a moist, mineral-matter-free basis. The terms "rank" and "coalification" cannot be used synonymously in reference to lignitic coal, as is often done in coals of higher rank. Coalification of various ingredients in lignitic coals ranges from very little evidence of metamorphic change in resin to the relatively advanced stage of fusinization.

Coalification.—Development of the important component anthraxylon from woody remains represents a more rapid metamorphic advance of plant substance to coal than is apparent in attritus, particularly the yellow translucent ingredients of attritus, spores, pollen, wax, cuticles, and resin. These plant substances have inherently low oxygen content. They very successfully resisted decay in the peat stage and reacted rather slowly to geochemical processes in the lignitic stage of coal formation. A xyloid lignite composed almost wholly of anthraxylon may be more coalified than attrital coal from the same deposit, but the xyloid coal is not necessarily at a higher-rank level. The highly volatile yellow translucent substances, present in attritus in large proportions, seem to have an important influence on the calorific rating of the coal, which is the basis of rank classification in the A.S.T.M. system previously described. The difference in calorific values of two coals, probably the result of their petrographic composition, is shown in Table 2, Arkansas and North

[9] Stopes, Marie C., On four visible ingredients in banded bituminous coal: Studies in the composition of coal. I: Roy. Soc. Proc., 1919 (B), vol. 90, p. 470, London, 1919.

[10] Kreulen, D. J. W., Elements of Coal Chemistry, pp. 34–37, Nijgh & Van Ditmar N. V., Rotterdam, 's-Gravenhage, 1948.

TABLE 2

COMPOSITION OF PEAT, BROWN COAL, AND LIGNITE OF VARIOUS GEOLOGICAL AGES OCCURRING IN THE UNITED STATES, AUSTRALIA, FRANCE, GREECE, AND GERMANY[1]

Rank	Petrographic variety	Geological age	Occurrence	Number of analyses averaged	Proximate analysis, moist, ash-free basis[2]			Calorific value, B.t.u. per pound
					Moisture	Volatile matter	Fixed carbon	Moist, ash-free basis[2]
Peat	—	Recent (Post glacial)	Kiel, Wis.	[3]	78.7	14.1	7.2	2050
Peat	—	Pleistocene (Glacial)	Bridgeville, Pa.	[3]	77.7	16.2	6.1	2100
Brown coal	Attrital	Miocene	Victoria, Australia[4]	[5]	66.8	17.7	15.5	3780
Brown coal	Attrital	Miocene	Victoria, Australia[4]		61.9	20.6	17.5	4230
Brown coal	Attrital	Miocene	Rhineland, Germany[6]	4	60.2	22.0	17.8	4430
Brown coal	Attrital	—	Auburn, Wash.	[3]	55.5	27.8	16.7	4570
Brown coal	Attrital[7]	Miocene[8]	Peloponnese, Greece	2	57.3	27.2	15.5	4800
Brown coal	Attrital	Miocene	Golpa and Leonhardt, Germany[6]	2	53.9	26.7	19.4	5440
Brown coal	Attrital	Miocene	Victoria, Australia[4]	[5]	51.0	26.5	22.5	5690
Brown coal	Attrital[7]	Miocene[8]	Attica, Greece	2	50.6	29.2	20.2	5840
Brown coal	Attrital	Oligocene	Helmstedt and Buddenstedt, Germany[6]	2	47.0	29.3	23.7	6590
Lignite	Attrital	Middle Eocene	Ione, Calif.	4	45.3	34.6	20.1	7120
Lignite	Attrital	Lower Eocene	Arkansas	10	42.4	33.6	24.0	7360
Lignite	Xyloid	Lower Eocene	Texas	11	36.4	31.4	32.2	8160
Lignite	Xyloid	Eocene	Pyrenees region, France[9]	[3]	39.6	26.0	34.4	8330
Lignite	Xyloid	Paleocene	North Dakota[10]	14	40.0	28.2	31.8	7340
Lignite	Xyloid	Paloecene	South Dakota[11]	6	40.1	28.6	31.3	7380

[1] Analyzed by Bureau of Mines unless otherwise stated.
[2] Moist refers to the coal or peat containing its natural bed moisture.
[3] One analysis.
[4] Edwards, A. B., The Composition of Victorian Brown Coals: Australian Inst. Min. Met. Proc., n.s. no. 140, p. 210, 1945.
[5] Average of unstated number of analyses.
[6] Aufhaüser, D., Brennstoff-Untersuchungen 1924–1925: Thermochemische Prufungs—und Versuchs-Anstalt, Dr. Aufhaüser, Hamburg.
[7] Classification based on microscopic examination of lump specimens.
[8] The exact age of the Greek lignites is not known with certainty. They may be pre-miocene or post-miocene in origin.
[9] Génie civil, vol. 124, pp. 58–59, 1947.
[10] The Fort Union lignites of North Dakota are now recognized to be Paleocene in age.
[11] The lignite deposits in the Ludlow formation of South Dakota formerly thought to be Upper Cretaceous in age are now assigned to the Paleocene. Dunbar, Carl O., Historical Geology, John Wiley & Sons, Inc., New York, p. 411, 1949.

Dakota lignites. Petrography of the North Dakota coals shows they are predominantly composed of anthraxylon and are relatively poor in the ingredients common to yellow translucent attritus. The Arkansas coal, on the other hand, is relatively low in anthraxylon content, and the attritus is unusually rich in resin, spores, cuticles, etc. This petrographic difference is reflected in higher volatile, lower fixed carbon, and slightly higher calorific values for the Arkansas coal.

Rank.—Since a great majority of lignite deposits do not consist wholly of anthraxylon or attritus, the level of rank attained, aside from influence of geological factors, is determined by the relative proportion of the components and the nature of phyteral ingredients in the attritus.

The feasibility of systematically classifying lignitic coals of different geological age and petrographic variety on the basis of calorific values is suggested in Table 2, which shows proximate analyses, moist ash-free basis, of certain peats, brown coals, and lignites occurring in the United States, Australia, France, Germany, and Greece. The coals are arranged in descending order of geological age from youngest peat to oldest lignite insofar as accuracy of available information permits. The rank assignment of the coals in column 1 is based on A.S.T.M. classification and common usage. In column 2 the classification of the American and Greek lignite and brown coal as to petrographic variety is based on petrographic study and that of the foreign coals from their general descriptions. For some of the coals listed, the number of analyses available are not adequate for conclusive data, and furthermore the table is incomplete in that all the Tertiary epochs are not represented. Nevertheless, even with the limited data, there is progressive order toward higher rank of the coal shown by decreasing moisture, increasing fixed carbon, and increasing calorific values. The least-marked change seems to be in volatile matter. The coals with moisture below 60 percent show very little change in volatile content. The best correlation shown in the table is calorific value with age of coal. There is only one very marked exception in this list to the general trend that the older the coal the higher its calorific value.

The South Dakota lignite is geologically the oldest shown in the table. This coal occurring in the very earliest Paleocene strata was until recently thought to be of Upper Cretaceous age. The Paleocene lignites of the Dakotas have lower calorific values than the younger Eocene lignite of Texas. This may be explained on the basis the Dakota lignites were not so deeply buried under sedimentary cover as the Texas lignite. The effect of difference in depth of burial is also shown in the case of the coals from Arkansas and Texas. In both instances, the deposits occur in basal Wilcox strata of early Eocene age. However, the Arkansas deposits are found farther up the embayment area, where the thickness of the Wilcox beds and overlying strata is much less than in Texas. As a consequence of considerably greater depth of sedimentary burial, Texas lignite is higher in rank than the Arkansas lignite.

Three factors affecting rank in lignitic coal have been discussed, namely petrographic composition, geological age, and depth of sedimentary burial. There remain to be mentioned two geologic phenomena that, at least regionally, cause variation in rank. Crustal disturbance of coal beds and associated strata

by folding, faulting or pronounced warping has the effect of speeding the development of rank. This has happened to the coal deposits of the Coos Bay area in southwestern Oregon [11] and the Puget Sound region of western Washington.[12] These coals occur in Tertiary strata of upper Eocene age. They are now subbituminous in rank and have been metamorphosed to this stage of coalification by normal pressure of overlying strata accompanied by moderate folding.

Table 3 shows the variation in rank of certain Greek coals of Tertiary age. The coal deposits represented by the analyses in the table occur in relatively shallow basins of limited areal extent. Several of the basins are considerably faulted. It is not at all certain that these coals were deposited in the same Tertiary epoch, but it seems evident from the range in calorific values as related

TABLE 3

VARIATION IN CALORIFIC VALUE OF GREEK COALS OF TERTIARY AGE AS RELATED TO GEOLOGIC STRUCTURE OF THE RESPECTIVE BASINS

Location of basin (county)	Geologic structure[1]	Analyses[2]	Proximate analyses, ash-free basis			
			Moisture	Volatile matter	Fixed carbon	Calorific value, B.t.u. per pound
Attica	Numerous faults of considerable magnitude	2	18.2	39.0	42.8	10,560
Euboea	Faulted	2	27.2	39.1	33.7	8,680
Attica	Faulted	1	29.4	37.5	33.1	8,430
Attica	Highly faulted. Dip of coal 15°–20°	3	32.0	35.7	32.3	8,210
Euboea	Bounded by large fault. Dip of coal 60°	2	39.7	36.6	23.7	6,800
Attica	Faulted	1	41.0	34.9	24.1	6,780
Attica	No faulting. Dip of coal 2°–3°	2	50.6	29.2	20.2	5,840
Peloponnese	No faulting. Coal horizontal	2	57.3	27.2	15.5	4,800

[1] Preliminary information from field survey in 1949 by W. G. Pierce, U.S.G.S., and A.L. Toenges, U.S.B.M.

[2] Standard face samples collected from mines in 1949 by A. L. Toenges, U.S.B.M., and W. G. Pierce, U.S.G.S., analyses by U.S.B.M.

to structural conditions in the individual basins that rank has been strongly influenced by crustal movement. At least one coal in the list, which incidentally was collected in an extremely faulted basin, has been converted to subituminous rank. The coal with lowest calorific value came, significantly enough, from a locality undisturbed by faulting.

Intrusive molten rock can be responsible for alteration in rank. Petrascheck cites localities in Bohemia, Czechoslovakia, and Netherlands East Indies where metamorphism of lignitic coals has been abetted by heat from igneous

[11] Toenges, Albert L., Dowd, James J., Turnbull, Louis A., Schopf, J. M., Cooper, H. M., Abernethy, R. F., Yancey, H. F., and Geer, M. R., Minable reserves, petrography, chemical characteristics, and washability tests of coal occurring in the Coos Bay Coal Field, Coos County, Oreg.: U. S. Bur. Mines Tech. Paper 707, p. 2, 1948.

[12] White, David, and Thiessen, Reinhardt, op. cit., p. 10.

rocks.[13] Figure 2 shows, by graphic arrangement, the petrographic data, chemical analyses, and physical tests of a coal core recovered from test hole in Gunnison County, Colo. The coal in this core showed progressive devolatilization from base to top of the bed. This is indicated in the analyses of upper and lower benches. Evidence of the variation in rank of this bed was strikingly seen in change in coloration of the anthraxylon from ruby red to yellowish red progressively downward in the bed. Confirmation was also present in change in streak of the coal from sooty black to brown in agreement with change in color of the anthraxylon. The variable quality of this coal is explained by the presence of a porphyry sill 6 feet above the coal. It can be safely assumed that heat from the original magma was responsible for differential devolatilization in the coal bed. There is evidence from physical tests that the temperature of the coal was raised approximately to the plastic range. Duration of the heat wave was not sufficient to uniformly devolatilize the coal, which was probably of lignitic rank at the time of the intrusion.

WAX AND RESINS IN LIGNITE.

Preliminary results of the investigation of yields of extractable wax from American lignites showed that certain samples from Arkansas and California gave much higher yields than other coals tested. In conjunction with the extraction tests a petrographic study of the lignites tested was undertaken. Thin-section examination revealed that coals which gave high yields of extractable products were composed predominantly of attritus. Lignites made up mostly of anthraxylon gave very low yields. The relationship of quantitative determinations of petrographic composition to benzene and benzene-alcohol extraction yields of several American lignites is shown in Table 1.

Attrital Lignite.—With evidence firmly established that attrital lignite is the most likely source of large yields of extractable wax, petrographic investigation was centered on this type of lignite to determine what ingredients in the attritus contributed to the extracted products. A column sample of attrital lignite from Ouachita County, Ark., was obtained for initial study. The pillar-like sample representing entire thickness of the deposit was 40 inches high and 15 inches on sides and weighed approximately 230 pounds. The coal was kept in natural bed-moist condition from field to laboratory and completely thin-sectioned and microscopically analyzed. The composition of the coal determined by this analysis is shown opposite item 8 in Table 1. A benzene extraction of a face sample cut from a channel in the coal face adjacent to the column yielded 6.7 percent solvent extract.

Particular attention was paid in the thin-section examination of the Ouachita County coal to the distribution of yellow translucent attritus in the column. The basal portion of the column to a height of 6 inches was conspicuously lean in content of yellow attritus. The chief constituent in this zone was orange translucent humic matter in fine shreds and particles. A rich

[13] Petrascheck, W. W., Die Metamorphose der Kohle und ihr Einfluss auf die sichtbaren Bestandteile dersellien. Aus den Sitzungsheichten der Osterr: Akad. Wiss. Wien Math.-naturwiss. Kl., Abt. I, Bd. 156, Heft 7 und 8, pp. 375–444, 1947.

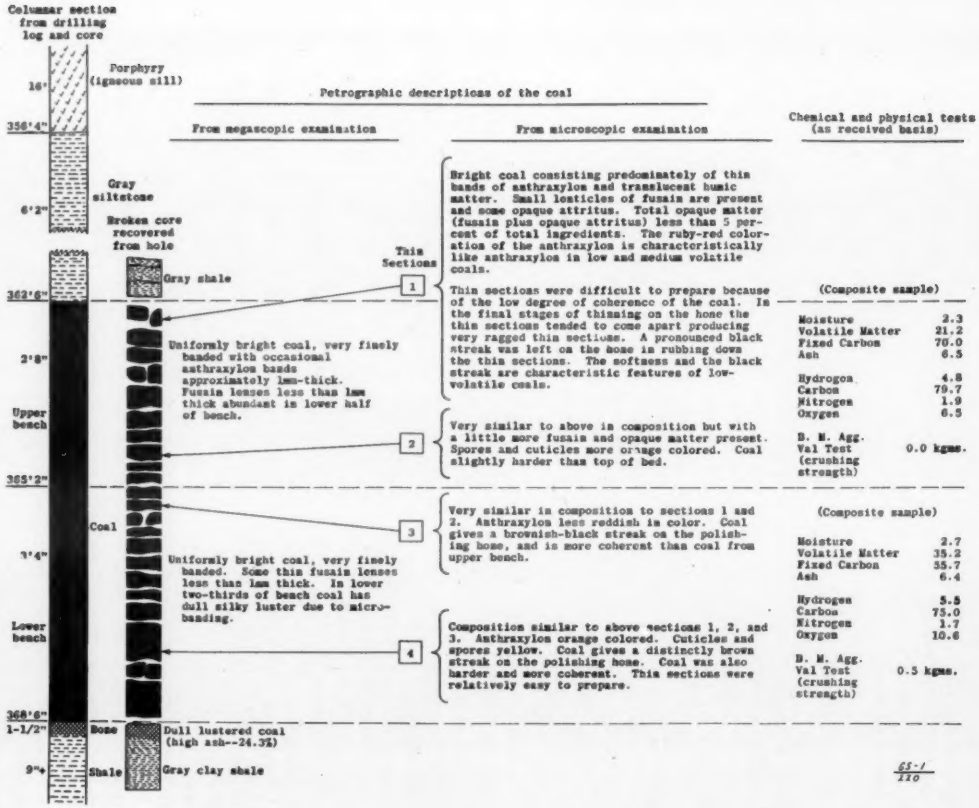
Columnar section from drilling log and core
Porphyry (igneous sill)
16'
356'4"
Gray siltstone
6'2"
Broken core recovered from hole
Gray shale
362'6"
Thin Sections
1
2'8"
Uniformly bright coal, very finely banded with occasional anthraxylon bands approximately 1mm-thick. Fusain lenses less than 1mm thick abundant in lower half of bench.
Upper bench
2
365'2"
Coal
3
7'4"
Uniformly bright coal, very finely banded. Some thin fusain lenses less than 1mm thick. In lower two-thirds of bench coal has dull silky luster due to micro-banding.
Lower bench
4
368'6"
1-1/2"
Bone
Dull lustered coal (high ash--24.3%)
9"+
Shale
Gray clay shale
Petrographic descriptions of the coal
From megascopic examination
From microscopic examination
Chemical and physical tests (as received basis)
Bright coal consisting predominately of thin bands of anthraxylon and translucent humic matter. Small lenticles of fusain are present and some opaque attritus. Total opaque matter (fusain plus opaque attritus) less than 5 percent of total ingredients. The ruby-red coloration of the anthraxylon is characteristically like anthraxylon in low and medium volatile coals.
Thin sections were difficult to prepare because of the low degree of coherence of the coal. In the final stages of thinning on the hone the thin sections tended to come apart producing very ragged thin sections. A pronounced black streak was left on the hone in rubbing down the thin sections. The softness and the black streak are characteristic features of low-volatile coals.
(Composite sample)
Moisture 2.3
Volatile Matter 21.2
Fixed Carbon 70.0
Ash 6.5
Hydrogen 4.8
Carbon 79.7
Nitrogen 1.9
Oxygen 6.5
B. M. Agg. Val Test (crushing strength) 0.0 kgms.
Very similar to above in composition but with a little more fusain and opaque matter present. Spores and cuticles more orange colored. Coal slightly harder than top of bed.
Very similar in composition to sections 1 and 2. Anthraxylon less reddish in color. Coal gives a brownish-black streak on the polishing hone, and is more coherent than coal from upper bench.
(Composite sample)
Moisture 2.7
Volatile Matter 35.2
Fixed Carbon 55.7
Ash 6.4
Hydrogen 5.5
Carbon 75.0
Nitrogen 1.7
Oxygen 10.6
B. M. Agg. Val Test (crushing strength) 0.5 kgms.
Composition similar to above sections 1, 2, and 3. Anthraxylon orange colored. Cuticles and spores yellow. Coal gives a distinctly brown streak on the polishing hone. Coal was also harder and more coherent. Thin sections were relatively easy to prepare.
65-1
110

FIG. 2. Thermal alteration of coal by magmatic intrusion as revealed by petrographic examination and chemical and physical tests of coal core recovered from Colorado test hole.

concentration of yellow attritus of comparatively large particle size was found in the middle section, Figure 3A. The information revealed by thin-section examination of the distribution of attrital ingredients was used as guide in cutting layer samples from the column for solvent extraction tests. Samples from the basal and the middle zones were extracted and yielded, respectively, 2.6 and 10.2 percent with benzene and 5.5 and 15.7 percent with benzene-alcohol solvents.

Yellow Translucent Attritus.—Although greater extraction yield from the middle zone sample was substantiating evidence that yellow attritus was mostly responsible for such high yields of solvent products, it remained to be discovered what elements in the attrital material were major contributors. The middle zone tested was unusual in composition with respect to large amount, 10.6 percent, of round yellow bodies. It was surmised these numerous yellow bodies were of significant importance in explaining the high extraction yield. Thiessen, in studying the microscopic composition of attrital lignites, distinguished between yellow and reddish bodies by calling them "light resinous" and "dark resinous" bodies. He believed the former were of a waxy nature and the latter composed of true resin.[14] Other coal petrographers and paleobotanists generally have concurred in this belief. Thiessen's "dark resinous" bodies are found most profusely associated with anthraxylon and the "light resinous" bodies in attritus.

Anthraxylon.—The importance of the "dark resinous" bodies in solvent extraction of lignite was tested with a sample of "pure" anthraxylon cut from another column of Arkansas lignite. Microscopic examination of the anthraxylon layer showed that about 21 percent of its volume consisted of "dark resinous" inclusions such as shown in Figure 3C. Standard solvent extraction tests yielded 0.3 percent of benzene extract and 3.1 percent of benzene-alcohol extract, item 16, Table 1. Their low degree of solubility in the organic solvents used raised a question as to the true "resinous" nature of the red bodies associated with anthraxylon. The greater solubility of "dark resinous" bodies in the benzene-alcohol mixture seemed significant.

The quantity of yellow translucent attritus in the Ouachita County lignite and particularly the large particle size of some of it made it seem possible that the coal matrix could be broken up and the ingredients isolated for examination. A sample was selected for this purpose from the middle zone of the column, which contained the very rich concentration of round yellow bodies. Preliminary trials at separation were made by carefully crushing and floating the coal in salt solutions of different specific gravities. This method of separation was not effective in securing any appreciable concentration of desired ingredients from the attritus.

Maceration of Attritus.—A method of chemical dissolution of coal by means of Schultz's solution (nitric acid and potassium chlorate) and a strong base is commonly used in laboratories to obtain spores, pollen, and other residue for microscopic study. To obtain a relatively large amount of insoluble material, about 4 pounds of dried lignite cut from the same middle zone of the column sample was treated with nitric acid diluted with water to make a 20 to

[14] White, David, and Thiessen, Reinhardt, op. cit., p. 231.

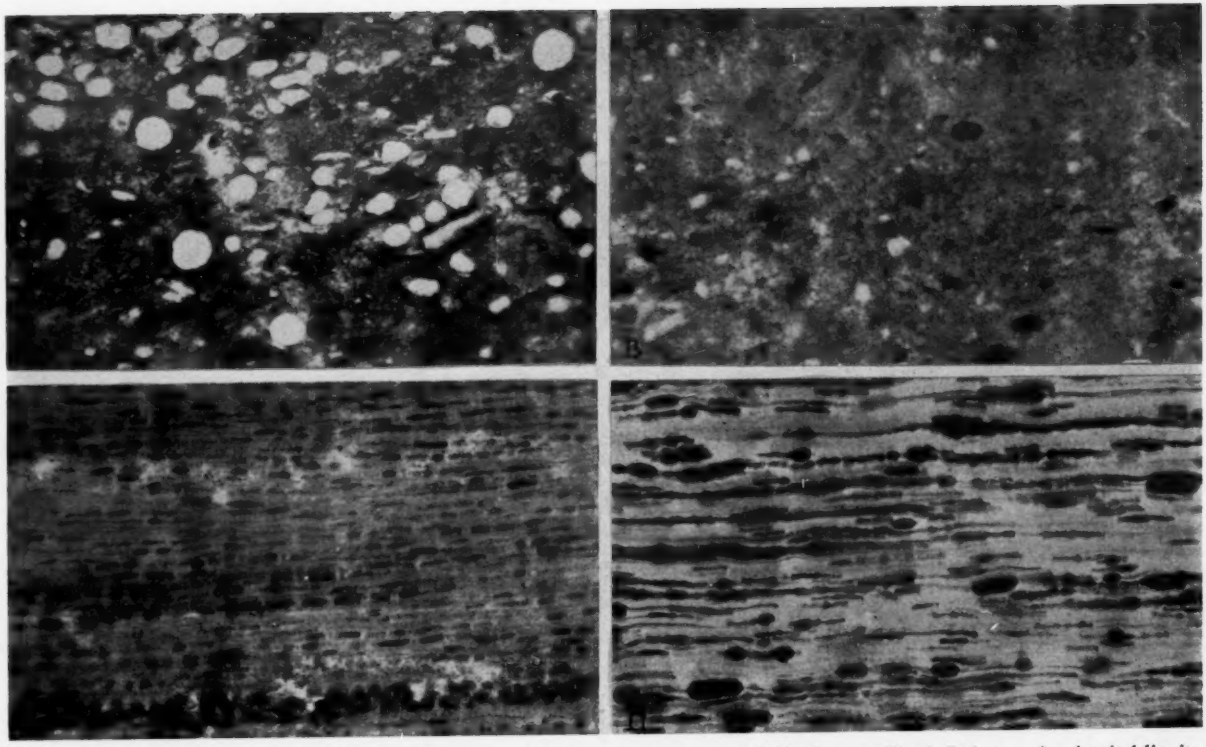

FIG. 3. Photomicrographs of typical thin sections of lignite from Arkansas, California, and North Dakota. A—Attrital lignite, Ouachita County, Ark. Yellow translucent attritus of large particle size. × 85. B—Attrital lignite, Amador County, Calif. Finely divided yellow translucent attritus. × 130. C—Anthraxylon with dark red inclusions, Dallas County, Ark. × 85. D—Anthraxylon with dark red inclusions, Ward County, N. Dak. × 170.

25 percent solution. Potassium chlorate was added to the acid solution to aid oxidation. Excessive effervescence and temperature rise were controlled by using a cold-water bath and diluting the mixture with water. When complete oxidation of the coal had been determined, the humic acids formed were removed by solution in ammonium hydroxide. The residue recovered was approximately 20 percent of the coal macerated. The residue was wet-screened with 180- and 325-mesh sieves to size-classify the particles of residue for microscopic examination.

A stereoscopic microscope was used to examine the sized residues under reflected light. The plus 180-mesh fraction was found to contain the following ingredients: (1) Yellow cuticular material, about 60 percent; (2) hard, dull, dark-brown, round rodlets with annulated surfaces and occasional lateral scars, about 30 percent; (3) hard, dull-red, vitreous rodlets, generally flat and possessing concave surface impressions, about 5 percent; (4) yellow and amber, irregularly shaped particles of lump-type resin, less than 3 percent; (5) yellow, amber, and red round bodies, less than 1 percent.

The composition of the 180- by 325-mesh fraction was quite different. The principal ingredients were round yellow, amber, and dark-red bodies. These bodies ranged in size from about 0.045 to 0.080 mm in diameter and comprised about 75 percent of the material present in the fraction. The remainder consisted of particles of cuticular matter and lump-type resin.

In the minus 325-mesh residue a small amount of the spherical bodies was present, but for the most part the ingredients consisted of very finely divided yellowish to reddish material of indefinite shape and unidentifiable specifically. Many spores and pollen grains were present, recognizable by structural form. Mineral matter, principally clay and silt particles, was associated with the organic attritus.

Photomicrographs of the three size fractions of residues are shown in Figure 4. Solvent extraction yields of the sized residues are shown in Table 4. The relatively high percentages of soluble products from each of the three sized residues leave little doubt as to the collective importance of these substances in lignite extraction, but these quantitative tests gave little information about the solubility of the various ingredients or the quality of the soluble product from the various types of ingredients.

TABLE 4

BENZENE AND BENZENE-ALCOHOL EXTRACTIONS OF RESIDUES FROM MACERATION OF SELECTED LAYER OF ATTRITAL LIGNITE FROM OUACHITA COUNTY, ARK.

Maceration residues				Extraction yields, percent			
				Benzene		Benzene-alcohol	
Size fraction	Percent of residue	Moisture, percent	Ash, percent	As tested	Dry ash-free	As tested	Dry ash-free
Plus 180 mesh	7.4	4.6	7.3	15.5	17.5	24.2	27.5
180 by 325	15.6	6.7	6.1	54.9	63.0	68.8	78.9
Minus 325 mesh	77.0	12.4	17.1	29.4	41.7	38.9	55.1

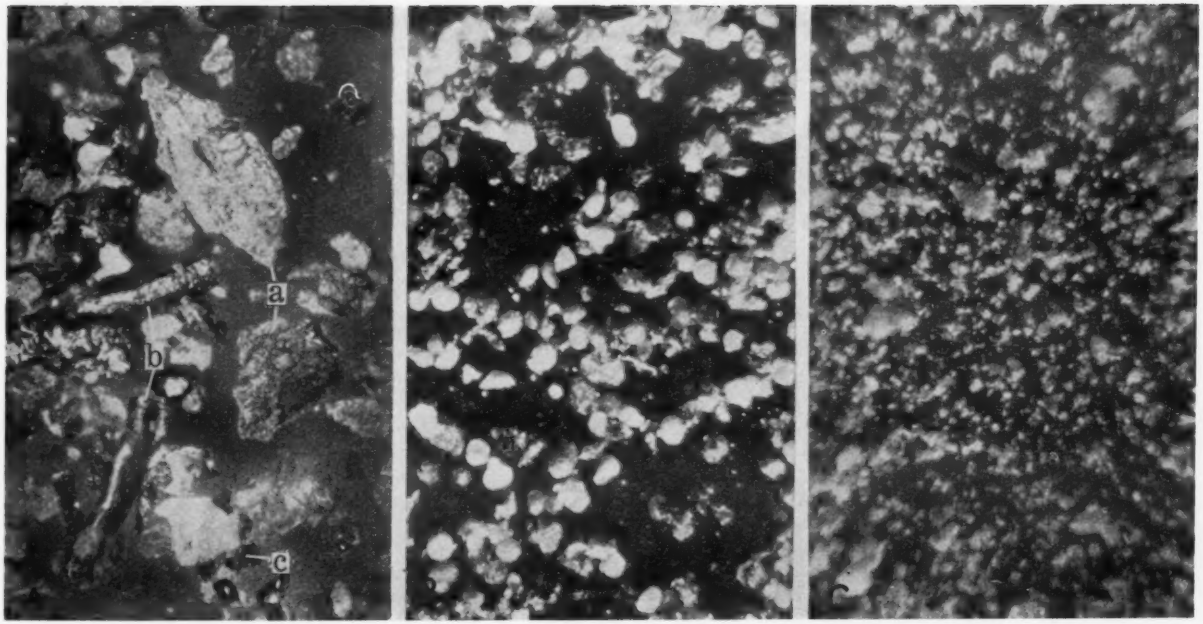

FIG. 4. Photomicrographs of screened residue recovered from maceration of attrital lignite. Columnar sample collected from deposit in Ouachita County, Ark. A—Plus 180 mesh residue, consists of: a, yellow cuticular particles; b, dark red vitreous, dull brown rodlets; c, irregular fragments of resinous material. × 40. B—180 by 325 mesh, consists of round, yellow amber, and dark red resin bodies; particles of cuticular material; and granular particles of resin. × 67. C—Minus 325 mesh consists of spores, pollen, and finely divided yellow translucent particles (undifferentiated); and translucent mineral matter. × 100.

EXAMINATION OF MACERATION RESIDUE AND SOLVENT EXTRACTS WITH MICROSCOPE HOT STAGE.

The melting temperature of wax and resin has considerable importance in evaluating their usefulness. The marked differences in the melting of waxes and resins offered a means of making a petrographic investigation of the extraction products and maceration residue from attrital coal. Use of a microscope hot stage seemed possible for this sort of work.

Description of Hot Stage.—A hot stage was constructed which consisted of a suspended nichrome ribbon with the hot junction of a thermocouple for temperature measurements welded to the bottom surface immediately below a shallow depression formed on the upper surface. The ribbon hot stage was enclosed in a removable metal chamber fitted with glass windows on side and top for admitting a strong beam of light and for viewing the stage with a stereoscopic microscope. The ribbon was heated with electric current controlled by a rheostat. Temperature calibration of the hot stage was done with chemical compounds of known melting point.

Method of Testing.—The objective of using the microscope hot stage was not to establish melting points with great accuracy, but rather to observe the effect of heat on substances as revealed by complete melting behavior. Very small samples of a few tenths milligram weight were observed. The material, usually in powder form, was spread on the hot-stage ribbon with the point of a specimen needle. Important points in the melting cycle of substances tested which were recorded in the microscopic observation were: (1) color of specimen before application of heat, (2) softening temperature, (3) temperature of initial flowage, (4) viscosity of melt, (5) color of melt, and (6) temperature of completed melting.

Preliminary tests made with commercial natural waxes and resins revealed the differences in melting characteristics of these two substances. The range between initial and complete melting of the waxes was generally only a few degrees. An exception to this rule was found in ozokerite from Galicia and a similar product from Utah called utahwax, both of which were slow-melting. All waxes tested melted completely at temperatures well under 100° C, Table 5. Melted wax was visually light colored, thin, and free-flowing. Tests of natural resins and resin from coals, in melting, showed pronounced differences from waxes. Initial melting of resin was never sharply defined and was always preceded by rounding of edges of particles, accompanied by slight surface swelling. This point was recorded as softening temperature. The second stage observed was formation of a globular mass from each particle of resin. As more heat was gradually applied, the globules eventually began to flatten and slowly flow together, forming a very viscous melt. The color of the resinous melts was usually darker than that of wax melts, but no significance could be tied to color. Some dark resins melted with extreme difficulty and formed very viscous melts. This was also true of certain pale-yellow resin hand-picked from coal, Table 5.

Study of the effect of heat on commercial waxes and resins suggested the probability that similar tests with the solvent extractions and maceration residue from lignite might show some correlation between the two.

TABLE 5

MELTING CHARACTERISTICS OF COMMERCIAL WAXES, COMMERCIAL RESINS PREPARED FROM COAL, AND LUMP-TYPE RESIN HAND-PICKED FROM COAL

Source	Sample	Color	Melting temperatures, ° C[1]	Characteristics of melt
		Commercial waxes		
Utah, Soldiers Summit	Ozokerite, refined	White	48–80	Clear, slow-flowing melt
Petroleum	Paraffin, white solid	White	60–62	Clear, colorless melt, free-flowing
Galicia, Boryslaw	Ozokerite, crude wax	Brown	64–70	Yellow, slow-flowing melt
Czechoslovakia	Montan wax from brown coal	Brown	73–74	Light-brown melt, free-flowing
California, Ione	Montan wax from lignite	Brown	73–75	Light-brown melt, free-flowing
Brazil, Parahyba	Carnauba wax from palm leaves	Yellow	73–75	Light-yellow melt, free-flowing
Arkansas, Malvern	Montan wax from lignite	Brown	80–83	Brown melt, free-flowing
Germany	Montan wax from brown coal	Brown	82–83	Brown melt, free-flowing
		Resins prepared from Utah coal		
Utah, Castlegate	Clarified resin[2]	Clear amber	170–175	Light-brown melt, slow-flowing
Utah, Castlegate	Fossil resin[2]	Clear amber	203–220	Brown melt, very viscous
Utah, Castlegate	Fossil resin[2]	Dark brown	218–220	Dark-brown melt, very viscous
Utah, Castlegate	Fossil wax[2]	Clear amber	212–245	Brown melt, slow-flowing
Utah, Castlegate	Fossil wax[2]	Yellow	225–243	Brown melt, slow-flowing
Utah, Castlegate	Asphalt resin[3]	Dark brown	255	Black, globular melt, no flowage
Utah, Stockton	Commercial resin[4]	Clear amber	207–226	Brown, viscous melt, slow-flowing
Utah, Stockton	Commercial resin[4]	Clear amber	217–235	Brown, viscous melt, slow-flowing

TABLE 5—*Continued*

Source	Sample	Color	Melting temperatures, ° C[1]	Characteristics of melt
		Lump-type resin hand-picked from coal		
Arkansas, Dallas Co.	Lump-type resin picked from lignite	Yellow granular	170–175	Brown melt, slow-flowing
Arkansas, Dallas Co.	Lump-type resin picked from lignite	Clear amber	170–196	Brown melt, slow-flowing
Alaska, Eska	Lump-type resin picked from bituminous coal	Clear amber	202–222	Brown melt, slow-flowing
Utah, Huntington	Lump-type resin picked from bituminous coal	Clear amber	206–224	Brown melt, slow-flowing
British Columbia, Merritt	Lump-type resin picked from bituminous coal	Clear amber	242–349	Dark-brown, melt, very viscous
India, Assam Province	Lump-type resin picked from bituminous coal	Amber color	260–270	Dark-brown, globular melt, no flowage
New Zealand, North Island	Lump-type resin picked from bituminous coal	Clear pale yellow	276–371	Dark-brown, globular melt, no flowage

[1] The lowest value representing each test is the temperature at which melting was first observed, and the higher value temperature at which the melting was complete. The temperature rise was kept at a constant low rate, and the size of each sample tested was about the same.

[2] Samples as designated and furnished by A. Naglevoort, An American Source of Natural Resins for the Paint and Varnish Industry: Chem. and Met. Eng., vol. 49, pp. 80–82, Oct. 1942.

[3] Sample furnished by the Combined Metals Reduction Co.

[4] Sample furnished by the U. S. Refining & Mining Co.

Before the melting tests are described, a brief explanation of the terms "solvent extractions" from lignite and "montan wax" is given to make clear the usage of the terms in this paper. Although both products are obtained with similar solvents and they have similar physical appearance, only the commercially obtained product is called "montan wax."

Chemical Constitution of Solvent Extracts.—Various analytical tests of the solvent extractions from lignites and of montan wax from domestic and European coals indicate that these substances are mixtures of "waxes," "resins," and "asphaltic" material. So far as industrial practices are known, montan wax of commerce is believed to be obtained with volatile solvents, such as benzene, xylene, and benzene mixed with alcohol in proportions up to equal amounts of each. The composition of the montan waxes may vary with different solvents used, but it seems probable also that the composition of montan wax might vary considerably because of differences in the petrographic constitution of the coal. The benzene extractions from Arkansas lignite, Table 1, contained more "resinous" material than similar extraction from California. Both coals are attrital type, but the California lignite contains very finely divided yellow attritus and little of the round, yellow, "resinous" bodies so common in the attritus of Arkansas lignite. The principal difference in the products from solvent extractions of both Arkansas and California lignite using benzene and the benzene-alcohol mixture seemed to be the greatly increased amount of "asphaltic" material in the product from the benzene-alcohol mixture.

Melting Characteristics of Montan Waxes and Solvent Extracts.—The melting characteristics of montan wax from Germany, Czechoslovakia, Arkansas, and California were tested on the microscope hot stage, Table 6. These products melted at temperatures between 73° and 83° C. All the melts were free-flowing, but some differences in viscosity were noted. The color of the melts was light brown. The melting behavior, in general, was quite similar to that of the commercial vegetable wax called carnauba wax. The products from the standard solvent laboratory extractions were tested. The benzene and the benzene-alcohol extractions from California lignite melted almost identically with montan wax from the same coal. The benzene-alcohol product melted at a slightly higher temperature and was a little more viscous. The benzene extractions from three Arkansas samples melted at temperatures from 76° to 94° C, and considerable difference was noted in the viscosity of the melts. The benzene-alcohol extractions from the same samples melted at temperatures from 86° to 135° C, and all melts were definitely viscous. The melting characteristics of the benzene-alcohol products from the Arkansas samples closely resembled some resin substances tested.

Testing was then continued, using the solvent extractions from the maceration residue of the Ouachita County coal, Table 6. The benzene extraction of the plus 180-mesh fraction melted at the lowest temperatures, 84°–102° C. Products of the other fractions melted at considerably higher temperatures up to 206° C. The melts were all quite viscous. The benzene-alcohol extractions from the same fractions behaved in melting very similarly to the benzene products. The most significant feature in these tests was the long temperature

TABLE 6

MELTING CHARACTERISTICS OF BENZENE AND BENZENE-ALCOHOL EXTRACTION PRODUCTS FROM LIGNITE, INGREDIENTS FROM LIGNITE, MACERATION RESIDUES, AND BENZENE SOLUBLE PRODUCTS FROM CERTAIN INGREDIENTS SELECTED FROM MACERATION RESIDUES

Source	Sample	Melting temperatures, °C.	Characteristics of melt
Products from benzene extraction of lignite and residues from macerated lignite			
Russia, Palatowa	Paper coal (Papierkohle) from Moscow liguitic coal basin	67–71	Light-brown melt, free flowing
California, Ione	Lignite from Amador County	74–79	Light-brown melt, free flowing
Greece, Ptolemais	Attrital-type brown coal	74–81	Light-brown melt, free flowing
Arkansas, Malvern	Column sample from American Dyewood Co. mine	76–84	Light-brown melt, free flowing
Arkansas, Malvern	Column sample from outcrop, Hot Spring County	80–83	Light-brown melt, free flowing
Arkansas, Ouachita County	Sample—6-inch layer from Old Big House mine column	88–94	Light-brown melt, slow flowing
Arkansas, Ouachita County	Plus 100-mesh maceration residue from above sample	84–102	Brown viscous melt, slow flowing
Arkansas, Ouachita County	180- × 325-mesh maceration residue, same sample	86–206	Brown viscous melt, slow flowing
Arkansas, Ouachita County	Minus 325-mesh maceration residue, same sample	150–173	Brown viscous melt, slow flowing
Products from benzene-alcohol extraction of lignite and residues from macerated lignite			
California, Ione	Lignite from Amador County	81–84	Brown melt, slow flowing
Arkansas, Malvern	Column sample from American Dyewood Co. mine	95–114	Brown melt, slow flowing
Arkansas, Malvern	Column sample from outcrop, Hot Spring County	111–131	Brown melt, slow flowing
Arkansas, Ouachita County	Sample—6-inch layer from Old Big House mine column	113–123	Brown melt, slow flowing
Arkansas, Ouachita County	Plus 180-mesh maceration residue, above sample	86–135	Dark-brown melt, slow flowing
Arkansas, Ouachita County	180- × 325-mesh maceration residue, above sample	94–230	Dark-brown melt, slow flowing
Arkansas, Ouachita County	Minus 325-mesh maceration residue, above sample	154–198	Dark-brown melt, slow flowing

TABLE 6—*Continued*

Source	Sample	Melting temperatures, ° C.	Characteristics of melt
	Ingredients from maceration residue of a selected 6-inch layer sample—Old Big House column[1]		
	Yellow cuticular material from the plus 180-mesh maceration residue	No melting	Darkened, 260° C; charred, 370° C; ashed, 500° C
	Round yellow bodies from the 180- × 325-mesh maceration residue	200–255	Brown viscous melt
	Round amber bodies from the 180- × 325-mesh maceration residue	209–267	Dark-brown globular melt
	Round dark red bodies from the 180- × 325-mesh maceration residue	350	Black globular melt
	Particles of lump-type resin, plus 180-mesh residue	170–200	Brown viscous melt
	Dark red vitreous rodlets plus, 180-mesh residue	No melting	Some softening 300° C, some swelling and tar 480° C
	Dull, dark brown rodlets, plus 180-mesh residue	No melting	Gray cellular ash 590° C
	Benzene soluble product from ingredients separated from maceration residue—Old Big House column[1]		
	Yellow cuticular material—hot, benzene-soluble product	72–78	Light yellowish melt, slow flowing
	Lump-type resin—hot, benzene-soluble product	178–218	Brown viscous melt
	Round bodies—yellow, amber, and dark red mixed— hot benzene-soluble product	195–280	Brown viscous melt

[1] Variation in shades of color was more or less characteristic of all types of ingredients found in the maceration residue. For the tests made, specimens typical of the color designated were selected.

range between initial and complete melting. Melting seemed to be intermittent in spite of uniform rate of heat increase. A conclusion was reached from these tests to the effect that benzene extraction of the plus 180-mesh fraction was the most "waxy."

Effect of Heat on Ingredients in Maceration Residue.—Considering the large particle size of this fraction, it seemed plausible the various ingredients could be isolated and tested. The hot stage was first used to test the effect of heat on individual specimens of the various ingredients. The dark-brown rodlets (Fig. 4) showed no effect from the heat until ashing temperature was reached. The red, vitreous rodlets developed a very slight swelling and a few beads of tarry exudation a few degrees below ashing temperature. Particles of cuticular matter charred and ashed but showed no signs of melting. The irregular fragments of resin and the round yellow and reddish resinous bodies had melting characteristics that were very similar to those of resin hand-picked from coal. Very little difference was noted in the melting temperatures of yellow and amber round resinous bodies, but the dark-red bodies formed a globular melted mass with no flowage at temperatures as high as 350° C. These experiments gave no positive hint as to the source of wax in the coal, but they did eliminate both the irregular particles of resin and the round resinous bodies, irrespective of color, from further consideration as waxes.

Melting Characteristics of Solvent Products of Maceration Residue.—Tests of the solubility of the different constituents in the plus 180-mesh residue seemed worthy of trial. Particles of the same substances were isolated and immersed in a small amount of benzene at boiling temperature; after a short period of solution, the benzene was filtered and evaporated. From the round resinous bodies and the lump-type resin a resinous residue of high melting temperature was obtained. No soluble residues were recovered from the rodlets. From the yellow cuticular material a light brownish residue was obtained which was relatively soft and had a waxy luster. The melting characteristics of this product were tested and found to be very similar to waxes from benzene extraction of lignites. This test indicated that cuticles were the source of the waxy element, at least in extractions from the Arkansas lignite.

A fairly large sample of papierkohle from the Moscow Basin in Russia was available for a comparative test. This lignitic coal is composed almost entirely of cuticles and in recognition of this fact is commonly called "leaf coal." An extraction test was made and a soluble product obtained. The melting tests of the waxy-appearing substance indicated it to be very similar to that obtained from cuticles in the Arkansas lignite. No similarity in the cuticles from these two coals of such vastly different geological age is implied, but the assumption is a reasonable one that in both instances the cuticular remains are composed in part of waxy substance just as are the cuticular tissues of living plants. The lignitic coal of the Moscow Basin is Mississippian in age; and, in view of this fact, it is an interesting point that the secretion of waxy substance in the cuticular coverings was achieved by plants as early as seven long geological periods removed from the present time and relatively near the very beginning of arborescent vegetation.

Petrographic variety	Color variation	Profile section (Megascopic)	Megascopic description (Surface examination)	Microscopic description (Thin section examination)	Typical quantitative determinations of petrographic composition. (Thin section analysis)	Typical photomicrographs	Magnifications	Typical solvent extraction yields. Benzene	Typical solvent extraction yields. Benzene-alcohol 80-20%
Xyloid	Brown to dark brown		Relatively hard, firmly consolidated, banded coal. Made up of alternating layers and lenses of smooth, semi-bright, and of dull, grainy coal. Occasional thin layer and lens of black, soft fusain. Most layers and lenses of all components are less than 1/4 inch thick. Occasional thick "woody" layers easily recognizable with unaided eye to be of wood derivation. Brownish streak. Wet surface, black; dry, dark brown.	Orange translucent bands and lentils of anthraxylon, the predominant coal component present. Anthraxylon commonly shows distinct cellular structure of woody tissue in transverse or longitudinal cross sectional view. Dark red inclusions common in some anthraxylon bands. Attritus contains opaque matter and particles of fusinite, but consists mostly of brownish red humic degradation matter in very fine shreds and particles. Yellow translucent attritus of minor importance. Occasional thin layers and lenses of fusain showing woody structure and mineralization.	Anthraxylon 61% Translucent attritus 27 Opaque attritus 9 Fusain 3		65x 35x 65x 335x	N. Dak. 1.2 Texas 2.0	2.8 4.2
Attritol	Brown to dark brown		Relatively hard, compact non-banded coal. Surface dull and grainy textured. Occasional thin layers and lenses of smooth textured semi-bright coal. Brownish streak. Wet surface, dark brown; dry, brown.	Consists mostly of brownish red humic degradation matter with thin layers and lenses of anthraxylon. Opaque attritus and fusinite common. Occasional layers and lentils of fusain. Yellow translucent attritus in subordinate amounts.	Anthraxylon 19.6% Translucent attritus 80.0 Opaque attritus .4 Fusain .0		50x	Ark. 7.6 Calif. 9.5	11.6 13.6
	Light brown		Tough, compact, non-banded coal. Surface dull and grainy. Occasional thin layer and lens of smooth textured coal. Occasionally particles of yellowish resin visible on surface. Slick "oily" trace on freshly cut surface. Light brown streak. Wet surface, brown; dry, light brown.	Brownish red humic matter and yellow translucent attritus with occasional thin layers and lentils of anthraxylon. Opaque matter of minor importance. Fusinite particles and fusain layers and lentils rare. Yellow translucent attritus very finely divided - particle size dominately less than 30 microns. Few large (30-80 microns) resinous bodies.	Anthraxylon 9.6% Translucent attritus 89.1 Opaque attritus .4 Fusain .0		50x	Ark. 8.9 Calif. 16.8	13.6 21.3
	Light brown		Tough, compact, non-banded coal. Surface dull and grainy. Occasional thin layer and lens of smooth textured coal. Grainy particles of resin common. Fragments of lump-type resin several millimeters in size occasionally found. Light brown streak. Wet surface, brown; dry, yellowish brown. Slick "oily" trace on freshly cut surface.	Brownish red humic matter and yellow translucent matter with occasional anthraxylon layer and lentils. Opaque matter and fusinite rare. Abundance of coarse yellow translucent attritus. Round resinous bodies and cuticular material prominent, and relatively of large size.	Anthraxylon 8.1% Translucent attritus 91.6 Opaque attritus .3 Fusain .0		35x	Ark. 10.2	13.7

FIG. 5. Petrographic descriptions and solvent extraction yields of different varieties of American lignite.

The cuticular particles from maceration residue of the Arkansas coal used in the tests were of exceptional size. In this coal most of the material of the same kind doubtless was much more finely divided, and it is quite likely that much wax was reduced to granular size and redistributed in the attritus accompanying complete degradation of cuticles in the peat stage. It is probable, too, that some wax in the coal may have been derived from degradation of epidermal layers of cortex tissues, particularly the suberin which in living plants functions similarly to cutin.

CONCLUSIONS BASED ON STUDY OF WAXES AND RESINS.

The petrographic study, described herein, of the wax and resinous ingredients in lignite does not provide all the answers to the problem of solvent extractable products. The exact chemical nature of the waxy, resinous and asphaltic elements is still to be determined for the extraction products of American lignites. However, certain tangible facts accrue from the work, which should be helpful in future investigations of wax-bearing coals. It is evident that only attrital lignite and brown coal give high yields of extractable products. This fact should be useful in search for new deposits. Attrital lignitic coals are quite easily distinguished in the field from the xyloid or "woody" variety. Attrital coals rich in yellow translucent attritus were found to give higher extraction yields than coals in which the attritus is composed chiefly of humic matter. The differences in petrographic composition of attrital coal are indicated in some instances by variation in surface color from light brown to very dark brown, and this point also should be helpful in field surveys for wax-bearing lignite. Variation in color because of differences in petrographic composition may not hold true for the younger brown coals but in any event the petrographic composition of any type lignitic coal can easily be determined by thin section examination, Figure 5. Thin section examination should also prove useful in exploring for wax yielding lignites by furnishing information of the potential resin content of the coal. Resin bodies are of such particle size that their relative abundance in the coal can be easily determined with the microscope and a high or low content of resin in the wax extraction predicted with reasonable sureness.

WAX AND RESIN IN LIVING PLANTS.

Vegetable wax is formed in growing plants in the integumentary parts, that is, the epidermal layers of leaves, seeds, berries, petioles, and stems. The outer protective covering of the epidermis, called the cuticle, is composed of cutin, a complex substance that has associated with it wax in the form of grains, rodlets, and crusty masses. Wax is also associated with the suberin, a fatty protective substance in cork tissues of plants.

Wax is excreted by the plants into the various epidermal tissues, where it serves principally as a waterproofing agent, preventing excessive moisture loss in warm, dry atmospheres and excessive water absorption in moist environments.

The waxy nature of cuticles is familiarly known in the peels of certain fruit, such as apples, plums, persimmons, and bananas. The waxy nature of the leaves of many kinds of plants is less well known, but the waxy coating of certain palm leaves and the broad floating leaf of the water lily is rather familiar. Wax does not seem to be secreted and stored to any extent internally in the xylary tissues of plants as is resin. There is never any waxy exudation from the stems of plants, so far as known.

Wax is produced most prolifically by trees, shrubs, herbs, canes, and grasses growing in warm and in dry climates. The leaves of the wax-bearing palm tree found in Brazil are the source of commercial carnauba wax. The wax coating of certain palm-tree leaves is 1 to 5 mm. thick. Vegetation native to the humid temperate climates is not conspicuously wax-bearing, although the berrylike fruit of the bayberry bush, a temperate-zone plant, is a source of commercial wax.

On the other hand, resin is the well-known product secreted by certain species of growing plants, the full function of which is not thoroughly understood. It occurs in greatest abundance stored in resin ducts and canals and in cell walls and cavities of xylary tissues. Resin is also found in cork, epidermal, and leaf tissues. Resin stored in canals and ducts of xylem and cortex tissues often becomes dark and hard and is believed to have different chemical properties from freshly secreted resin. The southern yellow pine is a striking example of a richly resinous plant; and coniferous trees, of which it is an example, are characteristically resinous. The pine exudes a large amount of resin—in reality an oleoresin—appearing as a yellowish, sticky substance on the bark and injured surfaces, and in the needle-like leaves. Oleoresin is the raw material from which are derived commercial products called naval stores, such as pine tar, turpentine, and rosin.

ORIGIN OF ATTRITAL AND XYLOID LIGNITE.

The prevailing occurrence of waxy matter in the cuticular coverings of reproductive and leafy organs of plants suggests a clue to the presence of wax in lignite. Leaves, seeds, fruit, berries, spores, pollen, and petioles are plant organs the remains of which are known to contribute heavily to attritus in coal. The protective coverings of these plant parts are usually very thin and constitute a small part of the organ, but the quantity of leaves, seeds, berries, fruit, spores, pollen etc., grown and shed annually by plants is large. The fleshy tissues in these organs decay rapidly, leaving the decay-resistant cuticular material to accumulate as attrital debris in the peat swamp. Thus peat and lignitic coals predominantly attrital in composition should logically be the best source for extractable wax. It would seem that deposits originating in tropical or subtropical climates might give higher wax yields than deposits accumulated from temperate-zone vegetation. Berry's [15] study of Wilcox flora established the fact that the Arkansas attrital lignite accumulated in a moist, subtropical climate.

[15] Berry, E. W., Lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, 480 pp., 1916.

Attrital lignite may have originated in swamp environment where decay of plant material went on at such a rapid rate that only decay-resistant attritus and very finely macerated woody tissue were preserved. Periodic renewal of fresh-water conditions by flooding from streams or heavy rains would promote rapid decay. Some attrital lignite may have accumulated in shallow fresh or brackish water pools in which not much vegetation actually grew but into which drifted, blew, or fell large quantities of debris shed from vegetation fringing the pool. Many of the Arkansas deposits may have originated in this manner. The thinness of the beds, shape of the deposits, absence of fusain, and small amount of opaque attritus suggest accumulation in shallow basins of open water.

The xyloid variety of lignitic coal in which the amount of anthraxylon is high and translucent attritus relatively low would quite naturally seem an unlikely source of extractable wax. Verification of this assumption is given in Table 1, which shows decreasing yield of extractable products from lignites of increasing anthraxylon content.

Xyloid lignite probably accumulated under conditions peculiar to stagnant-water peat swamps, where decay is somewhat retarded by the toxic water and much woody material is included in the debris. The slower the rate of vegetable decay, the more anthraxylon and proportionately less attritus accumulates, therefore lessening the possibility of wax and resin concentration. Texas lignite originated under conditions of slow decay, as indicated by thicker beds, more anthaxylon, and less tranluscent attritus than Arkansas attrital lignite. Appreciable amounts of fusain and opaque attritus characteristic of most xyloid lignites suggest occasional dry conditions in the peat swamp. The extensive lignite deposits of the Fort Union formation probably accumulated in great arboreal or tree-growing swamps much like our vast temperate-zone peat swamps of today. A preponderant amount of woody material and slow decay resulted in lignite composed predominantly of anthraxylon and relatively poor in attritus.

Coal Constitution and Miscellaneous Analysis Section,
U. S. Bureau of Mines,
Pittsburgh, Pa.,
June 19, 1950.

ILMENITE, MAGNETITE, HEMATITE, AND COPPER IN LAVAS OF THE KEWEENAWAN SERIES.[1]

HENRY R. CORNWALL.

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ABSTRACT.

The opaque minerals in ten lava flows of the Keweenawan series of Michigan were studied microscopically by the writer. The basaltic lavas, which range in thickness from 100 to 1,400 feet, contain ilmenite, magnetite, hematite, intergrowths of magnetite-ilmenite and ilmenite-hematite, copper sulfides, native copper, and pyrite. Variations of opaque iron minerals with thickness of flow are slight, but native copper predominates in the thinner flows and copper sulfides in the thickest. Pyrite occurs only in the thickest flow. Two groups of opaque minerals and their alteration products are distinguished. The earlier group includes magnetite, ilmenite, magnetite-ilmenite and ilmenite-hematite intergrowths, copper sulfides, and native copper. The later group includes hematite, native copper, chalcocite, pyrite, chlorite, and sphene. The second-generation minerals formed by the action of volatiles escaping from the lavas. The ratio of Ti to total Fe correlates with the degree of differentiation of the lavas, but the ratio of ferric to ferrous iron does not. The latter ratio was controlled primarily by the action of escaping volatiles.

INTRODUCTION.

THE writer has studied microscopically 47 polished sections of lavas of the Keweenawan series from the Michigan copper district. The study was made to determine what opaque minerals are present in the lavas, and what the relationships are of the opaque minerals to one another and to the silicates that make up the bulk of the rock. In particular the writer wanted to learn (1)

[1] Published by permission of the Director, U. S. Geological Survey.

whether magnetite, ilmenite, and hematite formed separately or as a solid-solution series, and (2) the relation of the opaque minerals to stage of differentiation, type of flow, and position in flow.

Polished sections were studied from 10 different flows ranging in thickness from 100 to 1,400 feet. Twenty-five sections of the Greenstone flow, 11 of the "Big" trap, and 1 or 2 each of 8 other flows were studied. The Greenstone flow and "Big" trap are the thickest, most differentiated lava flows in the Michigan copper district. Eight of the 10 flows studied, including the Greenstone flow and "Big" trap, contain layers, lenses, and spots of exceptionally coarse diabase, here called "pegmatitic facies" or "pegmatitic segregations," in a zone extending from the middle to the upper chill zone of the flow. All of the flows studied are basaltic in composition, and ophitic in texture. A typical flow contains about 60 percent calcic plagioclase (An_{50-70}), 25 percent augite plus olivine, 9 percent chlorite plus epidote, and 6 percent opaque minerals. A detailed petrologic investigation of five of the flows, including the Greenstone flow and "Big" trap, has recently been completed by the writer (3, 4),[2] and the Greenstone flow has been studied by Broderick (1).

OCCURRENCE OF OPAQUE MINERALS.

Ilmenite and Ilmenite-hematite Intergrowths.—All of the polished sections studied are listed in Table 1. The numbers indicate relative percentages of opaque minerals, as determined by visual estimates. All of the sections except the three amygdaloidal flow tops and the upper chill zone of the Greenstone flow contain ilmenite, and ilmenite is normally the predominant opaque mineral.

Ilmenite generally occurs in elongated grains that are interstitial to the silicates. The grains range in length from 0.01 to 5.0 millimeters and are largest in the thickest, coarsest-grained flows. The average length of the ilmenite grains is 0.1 to 0.5 mm in the thinner flows, and 0.5 to 1.0 mm in the thicker flows, and the ratio of length to width ranges from 2 to 7. In one ophitic basalt (Greenstone flow, depth[3] 235 feet), minute, 0.01-mm plates of ilmenite are graphically intergrown with a silicate.

In the Greenstone flow the ilmenite is predominantly homogeneous and unaltered. In six of the thinner flows studied, however, and in one polished section each from the Greenstone flow and "Big" trap the ilmenite contains minute blades and veinlets of specular hematite, 0.001 to 0.003 mm wide, and mostly oriented along one or two planes in any given grain (Fig. 1). The hematite probably formed by exsolution from the ilmenite during cooling as suggested by Ramdohr (12), Osborne (11), and Edwards (6).

Ilmenite is moderately to intensely veined and irregularly replaced by sphene in 15 of the 47 polished sections studied. This includes three sections from the thinner flows, three from the Greenstone flow, and nine from the "Big" trap. The sphene commonly forms parallel veinlets along one or two planes in the ilmenite, and locally forms irregular replacements around the fringes of ilmenite grains (Figs. 2, 3). In polished sections the sphene is

[2] Numbers in parentheses refer to Bibliography at end of paper.

[3] "Depth" as used in this paper refers to the stratigraphic depth below the top of the flow not the vertical depth below the surface ground.

TABLE 1.

RELATIVE PERCENTAGES OF OPAQUE MINERALS PRESENT IN LAVAS OF THE KEWEENAWAN SERIES.

Flow	Rock type	Depth below top (ft.)	Magnetite	Magnetite-ilmenite	Ilmenite	Ilmenite-hematite	Hematite	Sulfides[1]	Native copper
A	Amyg[2]	10					40	60	
A	Amyg	36					100	x[3]	
A	Basalt	71					100[4]	x	
A	Basalt	185		40	60				
A	Basalt	187		25	75			x	
A	Peg[5]	201		40	60			x	
A	Peg	211		70	20	10			x
A	Basalt	235			100			x	x
A	Peg	274		60	40			x	
A	Peg	345		55	45			x	
A	Basalt	365		40	60				
A	Peg	378		20	80				
A	Basalt	475		20	80				
A	Peg	578		40	60				
A	Peg	635		60	40				
A	Basalt	675		50	50				
A	Peg	684		30	70			x	
A	Basalt	765		25	75			x	
A	Basalt	810		8	92			x	
A	Basalt	865		15	85				
A	Basalt	905		20	80				
A	Basalt	945			100				
A	Basalt	985		10	90			x	
A	Basalt	1158		30	70				
A	Basalt	1185	5	25	70				
B	Amyg	0					100		
B	Peg	53		30	60		10		
B	Peg	74			40	20	40		
B	Peg	96	10		30	15	45		
B	Basalt	105	2		60		38		
B	Peg	125	5		55		40		x
B	Peg	184			30		70		
B	Basalt	205			40		60		
B	Basalt	249		30	60		10		
B	Basalt	341	5	20	15	45	15	x	
B	Basalt	400	5	5	70		20		
C	Peg			60	30		10		
D	Peg			45	35	10	10		
D	Basalt		5	15	60		20		
E	Peg			10	10	70	10		x
E	Basalt		5	15		80			
F	Peg			40	50	10			x
F	Basalt			30	5	55	10	x	
G	Peg			60	25	5	10		x
H	Peg				5	5	90		x
I	Basalt				70	20	10		
J	Basalt				60	25	15		

A Greenstone flow, ophitic basalt containing pegmatitic segregations, 1,300 feet thick where sampled.

B "Big" trap, ophitic basalt containing pegmatitic segregations, 400 feet thick where sampled.

C, D, E, F, G, H, I, J. Flows of ophitic basalt ranging in thickness from 100 to 225 feet. All except I and J contain pegmatitic segregations.

[1] Chalcocite, bornite, and chalcopyrite except for two specimens at depths of 71 and 187 feet in the Greenstone flow that also contain pyrite.

[2] Amygdaloidal andesite. [3] Present in small amounts.

[4] Hematite occurs for the most part as minute dendrites. [5] Pegmatitic facies.

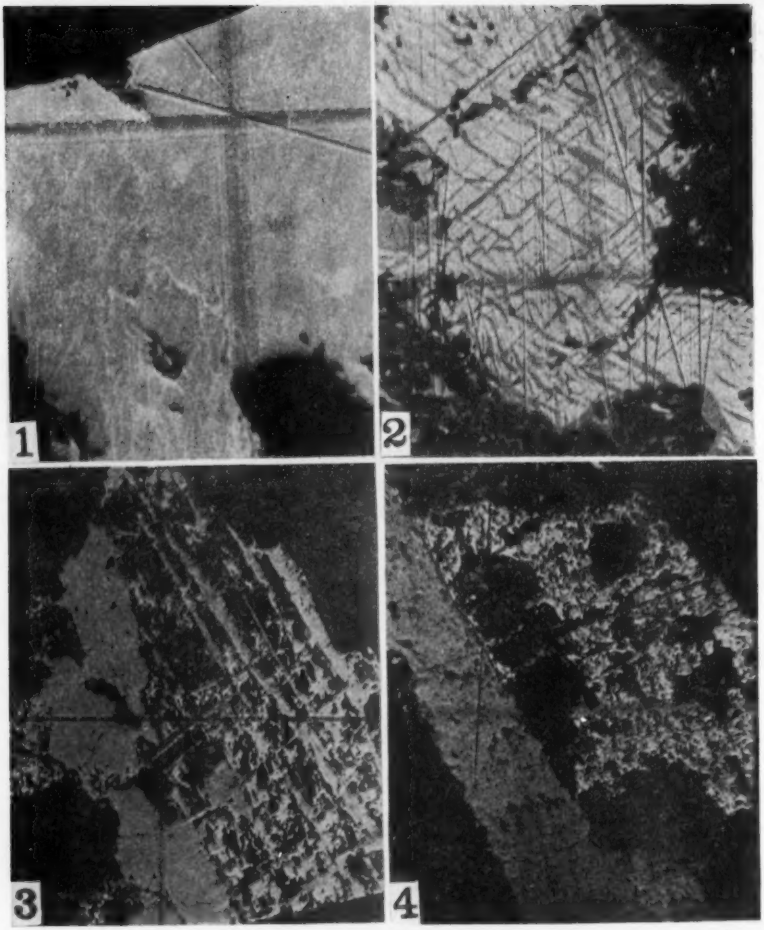

FIG. 1. Ilmenite (gray) with network of specular hematite (light gray) veins. Flow above Kearsarge conglomerate. × 860.

FIG. 2. Ilmenite (light gray) with network of veins and fringe of sphene (gray). "Big" trap, depth 184 feet. × 400, ×-nicols.

FIG. 3. Magnetite-ilmenite intergrowth, and irregular masses of ilmenite. Magnetite (black, etched) contains coarse plates of ilmenite (gray), and fine, irregular spots of specular hematite (light gray). Ilmenite is veined by sphene (dark gray). "Big" trap, depth 341 feet. × 144.

FIG. 4. Ilmenite (gray), and magnetite (etched, shiny black) partly replaced by specular hematite (white). Flow at South Range quarry. × 237.

brownish gray, and anisotropic with internal reflection. In thin sections it is translucent, anisotropic with slight or no extinction, and light brown to brownish gray in color. Specular hematite is in part intergrown with the sphene that veins and replaces the ilmenite in the "Big" trap. Since the veinlets of sphene, and locally associated hematite, are in places continuous with larger irregular replacements of ilmenite by the same minerals, it is probable that the veinlets themselves are replacements.

In one polished section of basalt at a stratigraphic depth of 341 feet in the "Big" trap, the ilmenite contains blades, 0.002 mm thick, of specular hematite and also larger veinlets of sphene. The sphene veinlets cut, and are clearly later than the specular hematite blades.

In addition to the sphene that occurs as veinlets and irregular replacements in ilmenite, sphene is also an accessory mineral in the amygdaloidal flows tops where it occurs as disseminated, discrete grains.

Magnetite and Magnetite-Ilmenite Intergrowths.—Magnetite, unaltered and not intergrown with ilmenite, was found in only 8 of the 47 polished sections. The largest amount in any one section was estimated to be 10 percent of the total opaque constituents present. The magnetite grains are similar in size to the ilmenite with which they are associated, but are commonly more nearly equidimensional. In all of the examples of homogeneous magnetite except the one in the Greenstone flow, the magnetite has been partly to nearly completely replaced by specular hematite as in Figure 4. No magnetite, either pure or intergrown with ilmenite or hematite, was found in the amygdaloidal flow tops.

Magnetite that contains oriented plates of ilmenite is common in the polished sections studied. The ilmenite plates are oriented along octahedral parting planes of the magnetite, and range in width from 0.001 to 0.10 mm. The magnetite-ilmenite grains range in size from 0.01 to 4.0 mm, and are comparable in size to the homogeneous ilmenite and magnetite grains with which they are associated. The magnetite-ilmenite grains tend to be idiomorphic and nearly equidimensional. It is also common, however, to find elongated grains of magnetite-ilmenite interstitial to the silicates of the rock. Lath-shaped plagioclase crystals commonly constitute 60 percent or more of the rock, and interstitial magnetite-ilmenite and ilmenite grains are generally elongated parallel to the plagioclase crystal boundaries. Locally single large crystals of magnetite-ilmenite and ilmenite contain poikiliticly included laths of plagioclase.

In 9 of the 32 polished sections in which magnetite-ilmenite intergrowths occur the magnetite is partly to completely replaced (Fig. 5) by chlorite and sphene, and in 8 of the sections the magnetite is partly to completely replaced by specular hematite. In all of the four sections from the "Big" trap that contain magnetite-ilmenite intergrowths the magnetite has been almost completely replaced by specular hematite. The replacement of magnetite by specular hematite, as illustrated in Figures 3 and 4, is generally spotty, but locally the specular hematite replaces magnetite along partings. In several sections the oriented ilmenite plates in magnetite-ilmenite grains have been partially altered to specular hematite.

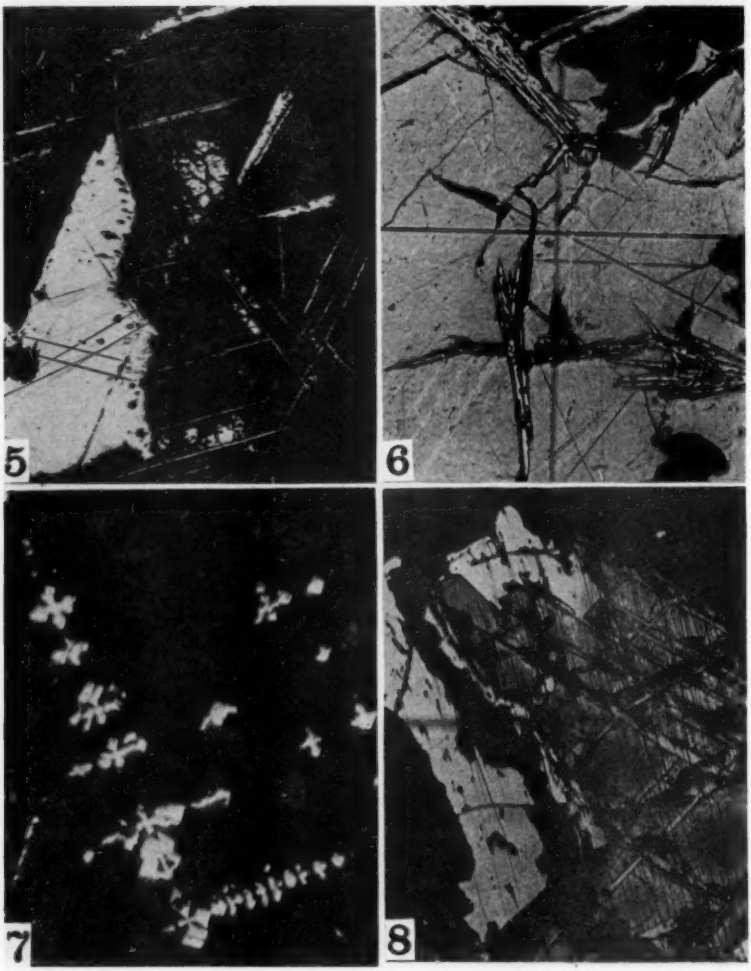

FIG. 5. Ilmenite (light gray), and magnetite-ilmenite intergrowth. The magnetite (irregular gray grains) has been mostly replaced by silicate (dark gray), leaving plates of ilmenite (light gray) that had formed along octahedral partings of magnetite. Greenstone flow, depth 675 feet. × 126.

FIG. 6. Amygdule filling of massive chalcocite (gray) that contains blades, in clusters, of specular hematite (white). Amygdaloidal Greenstone flow, depth 10 feet. × 127.

FIG. 7. Dendrites of specular hematite in fine-grained basalt. Greenstone flow, depth 71 feet. × 850.

Hematite.—Earthy and specular hematite occur as replacements of magnetite, ilmenite, and silicates, and also as fillings along minute cracks. The amygdaloidal tops of all the flows studied contain abundant hematite, both earthy and specular. All of the flows studied except the Greenstone commonly contain small amounts of specular hematite throughout. The "Big" trap contains abundant hematite, both earthy and specular, throughout. Where hematite is abundant the whole rock contains disseminated grains and seams of both the earthy and specular varieties.

Two occurrences of specular hematite in the top of the Greenstone flow are of particular interest. The amygdaloidal top at Cliff contains an intergrowth of chalcocite and specular hematite. Figure 6 (amygdaloid of the Greenstone flow, depth 10 feet) is a microphotograph of this intergrowth. The chalcocite occurs in seams and disseminated grains, both approximately 0.02 mm thick, and as fillings of vesicles up to 5 mm wide. The specular hematite is closely associated with the chalcocite and occurs in plates 0.2 to 1.5 mm long and 0.02 to 0.2 mm thick. The writer (3) has elsewhere presented evidence that the chalcocite and specular hematite mineralization of the Greenstone flow is syngenetic.

The second specimen of particular interest comes from the fine-grained basalt 71 feet below the top of the Greenstone flow. The rock contains disseminated 0.02-mm grains of pyrite, and dendrites of specular hematite that average 0.02 mm long and 0.005 mm wide. The specular hematite dendrites are shown in Figure 7. They closely resemble dendritic magnetite altered to hematite from Hawaii, figured by Butler and Burbank (2, Pl. 62); Edwards (6) has published a photograph of artificially produced dendritic magnetite crystals in a magnetite-rutile solid solution.

Sulfides and Native Copper.—Nineteen of the 47 polished sections studied by the writer contain disseminated grains, ranging from 0.001 to 0.15 mm in diameter, of native copper, chalcocite, covellite, bornite, and chalcopyrite. In the Greenstone flow the sulfides predominate, and native copper was only found in two sections. In the remaining 9 flows studied native copper predominates, and only two sections contain copper sulfides, in minute amounts. Two sections from the upper chill zone of the Greenstone flow, 71 and 187 feet stratigraphically below the top, contain abundant disseminated grains of pyrite, 0.01 to 0.02 mm wide, and the zone 50 to 75 feet below the top of the flow was found megascopically to contain abundant pyrite.

The copper sulfides observed in the polished sections are generally closely associated with ilmenite and magnetite. A number of grains of bornite and chalcopyrite were observed along the borders of and in contact with ilmenite or magnetite, and several round blebs, up to 0.05 mm wide, of chalcopyrite were observed in ilmenite and magnetite as well as in bornite. The close proximity of copper sulfides to ilmenite and magnetite may be explained by the fact that all of these metallic constituents formed for the most part later than the primary

FIG. 8. Magnetite-ilmenite intergrowth, and pure ilmenite. Magnetite (dark gray, etched) contains ilmenite (gray) along octahedral partings, and is fringed by ilmenite. Greenstone flow, depth 865 feet. ×165.

silicates, and are largely interstitial. Ödman (10) found that in the lavas of Mt. Elgon, British East Africa, copper sulfides occur mostly within crystals of magnetite and pyroxene. The disseminated native copper observed in several flows commonly occurs in discrete, nearly equidimensional grains, and is not related in its occurrence to ilmenite or magnetite.

Relation of Opaque Minerals to Position in Flow.—In all of the flows studied the opaque iron minerals present in the main body of the flow are ilmenite, magnetite, and hematite, or intergrowths of these minerals, with normally a predominance of ilmenite and magnetite-ilmenite. The amygdaloidal tops of all the flows, however, contain abundant earthy and specular hematite, small amounts of sphene, and no ilmenite or magnetite.

Butler and Burbank (2, p. 34–45) made a detailed study of the oxidation of lava tops in the Michigan copper district. They concluded that: ". . . both the oxidation and the concentration of iron (in the tops) were accomplished by gases escaping from the solidifying and crystallizing lava." Broderick (1) presented similar evidence for the increasing oxidation upward in flows by volatile transfer. The writer's findings, described above, are thus in agreement with the data of these authors, namely, that iron occurs predominantly as Fe_2O_3 in the amygdaloidal tops of the lavas. The writer also agrees that the oxidation was largely caused by the action of escaping gases. This problem will be discussed further under paragenesis.

The distribution of opaque iron minerals within the main part of a flow, that is, below the amygdaloidal top, was studied in detail only in the Greenstone flow and "Big" trap. The Greenstone, with the exception of the upper chill zone, is characterized by varying amounts of pure ilmenite and magnetite-ilmenite intergrowths. The lower half of the flow is a coarse-grained ophitic basalt that contains homogeneous ilmenite, predominantly, with small to moderate amounts of magnetite-ilmenite.

As mentioned in the introduction, above the ophitic basalt zone in the Greenstone flow is a zone containing pegmatitic segregations that extends from the base of the upper chill zone, at a depth of 200 feet, to slightly below the middle of the flow, at a depth of about 700 feet. The data in Table 1 show that both the pegmatitic facies and the basalt in the pegmatitic zone contain a higher proportion of magnetite-ilmenite to ilmenite than the basalt in the underlying ophitic basalt zone, and the proportion of magnetite-ilmenite is highest in the pegmatitic facies. These mineralogical relationships exist despite the fact that the TiO_2 content of the rock in the pegmatitic zone, and particularly within the pegmatitic layers themselves, is notably higher than that of the underlying ophitic basalt zone. The TiO_2 content of the basalt ranges from 1.08 percent (1, analysis 3152) near the base of the flow to 1.93 percent (1, analysis 3138) near the top of the pegmatitic zone, and the TiO_2 content of the pegmatitic facies ranges from 1.99 percent (3, analysis G297) to 4.30 percent (1, analysis 3140).

One might expect to find a higher proportion of ilmenite to magnetite in the rock of the pegmatitic zone because it is richer in TiO_2, but this tendency is offset by an even greater increase in the total amount of ilmenite plus magnetite and hematite in this zone. The amount of sphene in the rocks in

question is negligible. In Table 2 are shown the average amounts of modal ilmenite plus magnetite and hematite in 5 of the flows studied by the writer (3, 4). The pegmatitic zones, and particularly the pegmatitic layers contain the most opaque iron minerals. In the Greenstone flow the average ratio of modal ilmenite plus magnetite to TiO_2 is 1.47 in the ophitic basalt zone, 1.84 in the basalt of the pegmatitic zone, and 2.24 in the pegmatitic layers. The ratio was determined by dividing the average modal content shown in Table 2 by the weighted average TiO_2 content of that particular part of the flow, as determined from data published elsewhere (1, 3).

The concentration of TiO_2 in the pegmatitic zone, and especially in the pegmatitic layers themselves, in the Greenstone flow was more than compensated by an increased content of total iron in the same parts of the flow,

TABLE 2.

AVERAGE TOTAL COMBINED CONTENT OF MODAL ILMENITE, MAGNETITE, AND HEMATITE.

Flow	No. of analyses	Pegmatitic zone		Ophitic basalt zone
		Pegmatitic facies (percent)	Ophitic basalt (percent)	Ophitic basalt (percent)
Greenstone flow	10	6.2		
Greenstone flow	13		3.4	
Greenstone flow	14			1.8
"Big" trap	10	10.6		
"Big" trap	13		9.2	
"Big" trap	9			6.6
Average, 3 flows[1]	10	10.9		
Average, 3 flows	6		4.2	
Average, 3 flows	5			5.8
Total average[2]	30	9.2		
Total average	32		5.9	
Total average	28			4.1

[1] Average of the Mandan flow, a flow above the Kearsarge conglomerate, and a flow at the South Range quarry.

[2] Total average of all five flows, including the Greenstone flow and "Big" trap.

as shown by the analyses published by Broderick (1), and the writer (3), and the net result is reflected in the mineralogy by an increased proportion of magnetite-ilmenite to ilmenite alone.

Within the "Big" trap variations of the opaque iron minerals between the pegmatitic and ophitic basalt zones are not marked. There is slightly more ilmenite in the ophitic basalt zone than in the pegmatitic zone, whereas the pegmatitic zone contains more specular hematite. The only homogeneous ilmenite, unveined by sphene or specular hematite, occurs in the upper part of the pegmatitic zone. The occurrence of ilmenite, magnetite, and specular hematite in the pegmatitic facies is similar to that in the adjacent basalt. As shown in Table 2 the total amount of opaque iron minerals is slightly greater in the pegmatitic facies than in the adjacent basalt, and both contain sub-

stantially more of these minerals than the basalt of the underlying ophitic basalt zone.

Relation of Opaque Minerals to Thickness of Flow.—Eight of the 10 flows studied range in thickness from 100 to 225 feet. The "Big" trap is 400 feet and the Greenstone flow 1,300 feet thick where sampled. The Greenstone flow contains specular hematite only in its upper chill zone, whereas all of the other flows studied contain small to moderate amounts of specular hematite within the main body of the flow. The eight thinner flows contain all the

TABLE 3.

COMPARISON OF SIMILAR HORIZONS IN THE GREENSTONE FLOW AND "BIG" TRAP.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO_2	48.59	44.69	46.98	44.35	47.56	46.14	50.11	45.84
Al_2O_3	13.85	16.35	18.08	18.10	13.60	12.09	13.89	13.17
Fe_2O_3	4.64	6.03	2.93	8.02	2.43	9.80	3.75	11.18
FeO	7.37	6.58	7.92	4.67	8.95	5.70	10.42	4.65
MgO	7.62	7.25	6.19	7.30	6.49	6.06	3.77	4.70
CaO	6.96	9.11	10.30	9.38	12.71	9.84	6.56	10.69
Na_2O	2.26	2.63	2.40	2.43	2.50	3.48	3.39	2.69
K_2O	2.62	0.76	0.32	0.51	0.57	0.52	1.82	0.04
H_2O+	2.53	3.30	2.21	2.43	2.56	1.98	2.63	2.72
H_2O-	1.14	0.76	1.05	0.58	0.30	0.23	0.39	0.13
CO_2	0.12	0.04	0.06	0.03	0.00	0.06	0.02	0.19
TiO_2	2.02	2.18	1.26	1.90	2.15	3.52	2.74	3.47
P_2O_5	0.23	0.26	0.15	0.22	0.17	0.37	0.43	0.40
S	0.02	0.05	0.02	0.01	0.02	0.02	0.05	0.02
Cu	0.02	0.05	0.01	0.02	0.04	0.02	0.03	0.02
MnO	0.17	0.17	0.16	0.15	0.22	0.23	0.22	0.22
Total	100.16	100.21	100.04	100.10	100.27	100.06	100.22	100.13

(1) Basal chill zone of Greenstone flow, analysis G604, L. C. Peck, analyst, cited in Cornwall (3).

(2) Basal chill zone of "Big" trap, analysis T1716, L. C. Peck, analyst, cited in Cornwall (3).

(3) Ophitic basalt near center of Greenstone flow, analysis 3148, S. S. Goldich, analyst, cited in Broderick (1).

(4) Ophitic basalt near center of "Big" trap, analysis T1522, L. C. Peck, analyst, cited in Cornwall (3).

(5) Pegmatitic layer near center of Greenstone flow, analysis G559, L. C. Peck, analyst, cited in Cornwall (3).

(6) Pegmatitic layer near center of "Big" trap, analysis T1501, L. C. Peck, analyst, cited in Cornwall (3).

(7) Pegmatitic layer near top of Greenstone flow, analysis G149, L. C. Peck, analyst, cited in Cornwall (3).

(8) Pegmatitic layer near top of "Big" trap, analysis T1370, L. C. Peck, analyst, cited in Cornwall (3).

other opaque minerals present in the Greenstone, and in roughly the same proportions. In the thinner flows the ilmenite commonly contains minute blades and veinlets of specular hematite whereas the ilmenite in the Greenstone flow is almost entirely homogeneous; the magnetite is fresh in the Greenstone and partly altered to hematite in the thinner flows.

Primary copper, disseminated through the flows, occurs almost exclusively as native copper in all of the flows studied except the Greenstone flow. In the Greenstone flow the primary copper occurs predominantly as chalcocite,

bornite, and chalcopyrite. It is probable that sulfur escaped more rapidly and completely from the thinner flows during their cooling, and native copper formed because of a deficiency in sulfur at the time of crystallization.

Relation of Opaque Minerals to Composition of Flow.—The proportions of the various opaque iron minerals in the flows studied are similar with the exception of the "Big" trap. The flows typically contain more ilmenite than any other opaque mineral, and somewhat less, but still moderately abundant, magnetite-ilmenite. Hematite occurs only in small amounts. In the "Big" trap, however, earthy and specular hematite predominate, magnetite is practically absent, and the ilmenite is moderately to intensely veined and irregularly replaced by sphene.

Chemical data are available for comparison between the Greenstone flow and the "Big" trap. It is impossible to give an accurate average analysis for the "Big" trap as a whole because parts of the flow were not sampled. A comparison can be made with the Greenstone, however, by comparing the composition of similar horizons in the two flows as is done in Table 3.

The "Big" trap contains several percent less SiO_2 than the Greenstone flow, and has a much higher Fe_2O_3 to FeO ratio. There is also more TiO_2 in the "Big" trap than in the Greenstone, and slightly more total iron. Other differences in composition between the two flows are less clear-cut. The preponderance of hematite in the "Big" trap correlates with its abnormally high Fe_2O_3 to FeO ratio; and the relatively intense alteration of ilmenite to sphene correlates with its high TiO_2 content. The other flows studied by the writer have oxidized tops with abundant hematite, but in the "Big" trap the oxidation extends from top to bottom of the flow. The cause of this oxidation has been mentioned above and will be discussed further under paragenesis.

PARAGENESIS.

The normal paragenetic sequence in the lavas as determined by textural and veining relationships of the minerals is as follows:

1. Olivine, plagioclase.
2. Plagioclase, pyroxene.
3. Pyroxene, magnetite, ilmenite.
4. Magnetite, ilmenite, native copper, chalcopyrite, bornite.
5. Native copper, chalcocite, pyrite, specular and earthy hematite, sphene, chlorite, epidote, serpentine, iddingsite, prehnite, pumpellyite, quartz.

Ilmenite and magnetite occur most commonly as interstitial grains intergrown with plagioclase. A small part of the ilmenite and somewhat more of the magnetite occur as idiomorphic crystals. A few of the large grains of magnetite and ilmenite contain poikiliticly included laths of plagioclase. The pyroxene, predominantly augite, characteristically occurs in large grains with poikiliticly included plagioclase.

Some of the magnetite grains are microscopically homogeneous but most of the magnetite contains oriented plates of ilmenite, probably formed by exsolution along octahedral partings during cooling. The ilmenite is predominantly homogeneous, but some of it contains 0.002-mm oriented blades of

specular hematite, probably formed by exsolution during cooling. The magnetite and ilmenite are nearly contemporaneous. Locally magnetite fringes idiomorphic ilmenite, but more commonly ilmenite fringes magnetite crystals as in Figures 3 and 8.

Magnetite and ilmenite are moderately to intensely veined and irregularly replaced by chlorite, sphene, and specular and earthy hematite. Magnetite has been more intensely altered to hematite than ilmenite as is shown in Figures 3 and 4. Hematite also has replaced the silicates, especially olivine, along with chlorite, serpentine, iddingsite, epidote, prehnite, and pumpellyite. Hematite commonly occurs in cracks and veinlets that cross crystal boundaries, especially in the upper parts of flows, and the flow tops are commonly permeated with earthy hematite.

Chalcopyrite and bornite normally occur in rounded grains interstitial to silicates. There is a tendency for the sulfides to border grains of ilmenite and magnetite, and a few round grains of both bornite and chalcopyrite were noted included within magnetite and ilmenite. Where chalcopyrite and bornite are intergrown, the chalcopyrite veins the bornite and occurs as round grains within it. In the amygdaloidal top of the Green stone flow chalcocite and specular hematite are intergrown, and occur as fillings of vesicles and cracks, and as disseminated grains. Native copper occurs as discrete, nearly equidimensional grains, and is not closely associated in position with ilmenite or magnetite. Native copper does tend to be associated with prehnite, quartz, epidote, pumpellyite, and chlorite.

Evidence has been presented that hematite forms late during the crystallization of a flow. As cited above, Butler and Burbank (2) and Broderick (1) have shown that escaping volatiles were probably instrumental in oxidizing ferrous iron both in the magma and in the already solid crystals. Sosman and Hostetter (14) found experimentally that an increase in the partial pressure of O_2 caused hematite to form in place of magnetite. and Kennedy (9) recently showed that the Fe_2O_3 to FeO ratio in basaltic magma depends on the partial pressure of O_2 in equilibrium with the magma.

In deep-seated intrusives the partial pressure of O_2 builds up as the total volatile pressure increases during crystallization, but in lavas the total volatile pressure is low and nearly constant because the lavas are exposed to the atmosphere. Therefore, as Kennedy (9) points out, deep-seated gabbros should have higher Fe_2O_3 to FeO ratios than lavas, but chemical data indicate that this is not so. The lavas of the Michigan copper district, of which analyses have been obtained by Butler and Burbank (2), Broderick (1), and the writer (3), in general have high Fe_2O_3 to FeO ratios, and the ratio sharply increases from bottom to top of the flow.

Daly's (5) table of average compositions of igneous rocks also shows that extrusive basalts have a higher ferric to ferrous iron ratio than intrusive gabbros. His average of 198 basalts contains 5.38 percent Fe_2O_3 and 6.37 percent FeO, and his average of 41 gabbros contains 3.16 percent Fe_2O_3 and 5.95 percent FeO. Eleven extrusive melaphyres also have a higher ferric to ferrous iron ratio than the gabbros, but for 41 plateau basalts the ratio is lower. As

pointed out above there is a marked change in the ferric to ferrous iron ratio from bottom to top of flows, and inadequate composite sampling may have caused the variations in published analyses to be greater than they should.

The increase of oxidation of the iron during crystallization in lavas may be explained in part at least by drop in temperature which increases the oxidizing effect of O_2. This effect, clearly demonstrated experimentally by Kennedy (9), is partially offset by a decrease in the partial pressure of O_2 with a drop in temperature due to a decrease in the dissociation of H_2O, the principal volatile constituent in equilibrium with the lava. Using Kennedy's (9) data the writer has calculated the ferric and ferrous iron contents at atmospheric pressure of a basaltic magma in equilibrium with H_2O and its dissociation products, H_2 and O_2. At 1,200 degrees centigrade a magma with a content of 7.0 molecular percent FeO contains 1.95 molecular percent Fe_2O_3, while at 1,100 degrees centigrade a magma with 7.0 molecular percent FeO contains 3.70 molecular percent Fe_2O_3.

A drop in temperature of 100 degrees centigrade, therefore, has a marked effect on the Fe_2O_3 to FeO ratio of basaltic magma. The similar chemical composition, however, of the early- and late-forming solid fractions of the flows indicates that the temperature did not drop as much as 100 degrees during most of the solidification period. The writer has estimated by use of Hess' (8) curve for temperature of magma plotted against molecular percent of enstatite that the temperature of the magma of the Greenstone flow only dropped 25 degrees centigrade during almost the entire crystallization of the flow. A significant temperature drop probably occurred only in the gases that separated from the magma and migrated upward into the relatively cool chill zone, and in the residual hydrothermal solutions remaining after the flow was essentially solid. Only in the two thickest flows in the district, the Greenstone flow and "Big" trap, was there a residual granophyric magma, constituting less than one percent of the entire flow, that crystallized at a temperature considerably below that of the rest of the flow.

Probably the most important factor in the oxidation of lavas is that when bubbles form in the lavas the vapor does not remain in equilibrium with crystals and melt, but migrates upward into a new environment both as to composition and as to temperature. Because of lower temperature and inequilibrium the O_2 in the gases reacts with iron-bearing minerals, and forms hematite. The intensity of the reaction depends on the amount of volatiles that escape, the rate of cooling of the lava, and the rate at which the gases migrate through the mush of crystals and lava, and along cracks through the solid, upper chill zone.

In intrusives, volatiles vaporize to form bubbles only at shallow depths, and the bubbles do not migrate as freely as in the lavas. Incipient alteration of iron-bearing minerals to hematite in intrusives is probably due to increase in the partial pressure of O_2 along with an increase in total volatile pressure during crystallization. Schwartz (13) mentions incipient alteration of magnetite to hematite in the Duluth gabbro. He believes this was due to weathering, but in view of the apparent magmatic source for such oxidation in the

lavas of the Michigan copper district, it is perhaps more probable that the oxidation of the Duluth gabbro was also magmatic in origin, and due to an increase in volatile pressure during crystallization.

DIFFERENTIATION AND THE OCCURRENCE OF FE AND TI.

The writer (3, 4) has shown that the ratio of total iron oxides to magnesia provides a reliable index of the degree of differentiation of basaltic lavas in the Michigan copper district. Wager and Deer (15), and Walker and Poldervaart (16) have likewise found that in the Skaergaard gabbro, and in the Karroo dolerites the degree of differentiation is best shown by the ratio of total iron oxides to magnesia.

Evrard (7), in a recent study of the titaniferous magnetites and associated anorthosite and gabbro of the Adirondacks, has used the molecular ratio of TiO_2 to FeO plus Fe_2O_3 plus TiO_2 as an indication of degree of differentiation; and against this ratio he has plotted the molecular ratio of Fe_2O_3 to FeO plus Fe_2O_3. He found a systematic variation of the ferric to ferrous oxide ratio as the ratio of titanium to total iron increased; and the most differentiated magmatic product, the iron ore, has the highest ferric to ferrous oxide ratio. As discussed above, this relationship is to be expected in intrusives, because as crystallization and differentiation proceed there is an increase in the total volatile pressure with a consequent increase of the partial pressure of O_2, which causes an increased oxidation of the iron in the magma.

In Figure 9 the writer has plotted the molecular ratios $\frac{TiO_2}{FeO+Fe_2O_3+TiO_2}$ and $\frac{Fe_2O_3}{FeO+Fe_2O_3}$ against the weight-percent ratio $\frac{FeO+Fe_2O_3}{MgO+FeO+Fe_2O_3}$ for composite analyses of typical basaltic lavas of the Keweenawan series of the Michigan copper district. The ratio $\frac{TiO_2}{FeO+Fe_2O_3+TiO_2}$ correlates closely with the ratio $\frac{FeO+Fe_2O_3}{MgO+FeO+Fe_2O_3}$; the two ratios increase together. Variations in the ratio $\frac{Fe_2O_3}{FeO+Fe_2O_3}$, on the other hand, are quite irregular. The same relations hold for detailed comparisons within flows, as shown by analyses obtained by Broderick (1) and the writer (3, 4) of the "Big" trap, Kearsarge flow, and Greenstone flow.

Evrard's (7) postulate that the ratio of titanium oxide to total iron oxides increases with increased differentiation is thus substantiated by the chemical data on the lavas of the Keweenawan series of Michigan. The ratio of ferric to ferrous oxide in the lavas of the Keweenawan series, however, does not increase with increased differentiation. As discussed under paragenesis, the ferric to ferrous oxide ratio in lavas is apparently determined by factors related to the vaporization and escape of gases, and does not necessarily have any relation to the degree of differentiation of the lava.

SOLID SOLUTION OF FeO, Fe_2O_3, AND TiO_2 IN LAVAS.

Edwards (6), Ödman (10), Ramdohr (12), and others have cited occurrences in lavas of magnetite with a high TiO_2 content that is microscopically homogeneous even with the highest magnifications. Ramdohr (12) describes homogeneous magnetite that contains 11 percent TiO_2 in a basalt. He states, however, that the titaniferous magnetite in most lavas, and in all deep-seated intrusives contains intergrowths of ilmenite.

It is the opinion of the above-mentioned authors, based both on a study

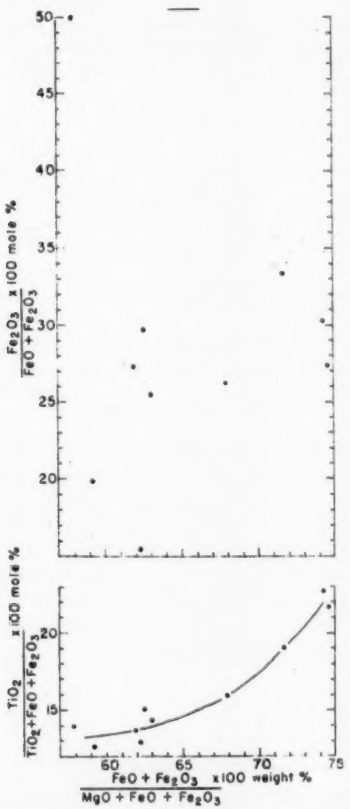

FIG. 9. Molecular ratios (ordinates) used by Evrard (7) to indicate stage of differentiation, plotted against the weight-percent ratio (abscissae) used by Wager and Deer (15), Walker and Poldervaart (16), and the writer (4). Chemical data obtained from composite analyses, cited by Broderick (1), of 10 basaltic flows of the Keweenawan series of Michigan.

of natural occurrences and experimental work, that magnetite and ilmenite form a complete solid solution series at high temperatures, and that with rapid cooling the solid solution is preserved. These authors have similarly found that hematite and ilmenite form a solid solution at high temperatures that is preserved by rapid cooling. Magnetite and ilmenite are more immiscible at low temperatures than hematite and ilmenite. Exsolution intergrowths of ilmenite and magnetite are more prevalent and coarser than those of hematite and ilmenite both because of greater immiscibility, and because ilmenite exsolves from magnetite at a higher temperature when the rate of solid diffusion is greater.

The lavas of the Keweenawan series studied by the writer do not contain complete solid solutions of magnetite and ilmenite or hematite and ilmenite. All of the flows contain either intergrowths of magnetite and ilmenite, ilmenite and hematite, or both. The amounts of ilmenite and sphene present, either alone or as intergrowths, are adequate to account for the total titanium present. No flows less than 100 feet thick were studied. Such thinner flows chilled more rapidly and may contain solid solutions of magnetite and ilmenite or hematite and ilmenite. The amygdaloidal, chilled tops of the flows studied contain hematite exclusively, and this hematite may contain TiO_2 in solid solution although sphene is also commonly present in small to moderate amounts. The one basal chill zone specimen studied ("Big" trap, depth 400 feet), contains predominantly ilmenite and specular hematite, but also a small amount of magnetite (partly altered to hematite) with included plates of ilmenite. Thus, even in the quickly chilled margin of a flow, cooling was not sufficiently rapid to prevent the development of ilmenite plates in magnetite.

ACKNOWLEDGMENTS.

The work embodied in this study was carried out for the U. S. Geological Survey as a part of its program in the Michigan copper district.

The microscopic work for this paper was done in the laboratory of Professor Edward Sampson at Princeton University. The writer thanks Prof. Sampson for his helpful suggestions and assistance, and A. F. Buddington, G. T. Faust and R. A. Weeks of the Geological Survey for critically reading the manuscript. The writer is grateful to the officials of the Calumet and Hecla Consolidated Copper Company for permission to collect specimens and samples used in this study from their diamond drill cores.

U. S. GEOLOGICAL SURVEY,
CALUMET, MICH.,
Sept. 25, 1950.

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THE INFLUENCE OF THE IMMERSION MEDIUM ON THE ROTATION PROPERTIES OF ANISOTROPIC MINERALS IN REFLECTED LIGHT.

EUGENE N. CAMERON.

ABSTRACT.

The rotation of the plane of polarization of incident light produced by reflection from a polished surface, cleavage, or crystal face of an anisotropic mineral changes as the immersion medium (oil, water, air) is varied. For a given mineral the changes produced are functions of the optical constants of the mineral and are therefore specific properties. This paper discusses the principles underlying changes in angles of rotation and related rotation properties with variation in the immersion medium and the possible applications of the changes to the study of minerals in reflected light. Preliminary observations suggest that the changes can be used as an aid in identifying ore minerals.

THE rotation of the plane of polarization of vertically incident light produced by a polished surface of an anisotropic mineral is a well known phenomenon, and its use to distinguish isotropic from anisotropic opaque minerals is part of the standard practice of mineragraphy. The causes of rotation, however, are less widely understood, and the phenomenon has therefore not been used to full advantage in the identification of ore minerals. Polarization figures and certain properties of anisotropic minerals dependent on rotation are discussed in a paper by the writer and L. H. Green.[1] Properties discussed in that paper are those determinable when the immersion medium employed is air, as is usual in mineragraphic work. The purpose of the present article is to discuss the changes in rotation properties produced by varying the immersion medium and to suggest the applications thereof to identification of minerals.

The optical principles underlying the phenomena of reflection are considerably simpler for transparent anisotropic minerals than for absorbing (opaque) anisotropic minerals. For this reason it is desirable to consider the transparent minerals first. In general, a ray vertically incident on a polished section of a transparent anisotropic mineral is broken into two rays vibrating at right angles to one another and having indices n_1 and n_2 that vary according to the mineral and according to the crystallographic orientation of the polished section. For a uniaxial mineral, the usual optical relations hold; i.e., one of the rays will be vibrating in a direction parallel to the plane of the horizontal crystallographic axes, and the index of refraction corresponding to this direction will be equal to ω; the other ray will be vibrating in a direction parallel to the projected trace of the c-axis, and the index of refraction corresponding to this direction will depend on the angle between the polished surface and the

[1] Cameron, E. N., and Green, L. H., Polarization figures and rotation properties in reflected light and their application to the identification of ore minerals: ECON. GEOL., vol. 45, no. 8, 1950.

c-axis. If the plate is parallel to the c-axis, the index of refraction will be equal to ϵ. For biaxial minerals the values of n_1 and n_2 will likewise vary with orientation in the usual way.

The two components of the incident ray parallel to the vibration directions of the mineral section are partly reflected but not in equal amounts. Owing to this, the single plane-polarized ray produced by combination of the two reflected parts will not in general be vibrating in the same plane as the incident ray but will be vibrating in a plane that will differ in azimuth from that of the incident ray. The angle between the vibration planes of the incident and reflected rays is a measure of the rotation produced by reflection. The rotation is maximum when the two vibration directions of the mineral lie at 45 degrees to the plane of the polarizer.

The maximum amount of rotation of the plane of vibration produced by reflection at the surface of an anisotropic transparent mineral is a function of the indices of refraction corresponding to the two vibration directions of the mineral section, the difference between the two indices, and the index of refraction of the immersion medium, which may be air, water, or oil. The relationship when the two vibration directions of the mineral section lie at 45 degrees to the plane of the polarizer is expressed in the equation

$$\text{Tan } \psi = \frac{n_0(n_1 - n_2)}{n_1 n_2 - n_0^2}. \qquad (1)$$

In this equation, ψ is the angle of rotation of the plane of vibration due to reflection; n_1 and n_2 are, respectively, the lesser and the greater indices of refraction of the mineral section, and n_0 is the index of refraction of the immersion medium. It is evident from the equation that with a given immersion medium, ψ will increase with the birefringence of the mineral section. It will likewise increase as the difference between the product of the indices of refraction corresponding to the two vibration directions of the mineral section and the square of the index of the immersion medium decreases. When $n_1 n_2 = n_0^2$, tan ψ becomes infinity, and ψ becomes 90°. It follows that the angle of rotation produced by a given mineral section may be varied at will by changing the immersion medium. This relationship has been pointed out by Schneiderhöhn and Ramdohr and by Berek,[2] but its possible use in mineral identification has never been explored.

In Table I, both calculated and observed values of the angles of rotation are given for five transparent anisotropic minerals. The technique and theory of measurement are described in the article by the writer and L. H. Green mentioned above. In the present work, however, a 95 × Spencer achromatic oil immersion objective has been used for measurements in oil. For cassiterite, rutile, and octahedrite, values in air and in oil are given. For quartz and calcite values in air and water are given. The reflectivities of these two minerals in oil are so low that satisfactory measurements of the angles of

[2] Schneiderhöhn, H., and Ramdohr, P., Lehrbuch der Erzmikroskopie, erster Band, erste Hälfte, p. 146, Gebrüder Borntraeger, Berlin, 1934. Berek, M., Optische Messmethoden im polarisierten Auflicht: Fortschr. Mineralogie, Petrographie, und Kristallographie, vol. 22, pp. 33–34, 93–94, 1937.

rotation cannot be made. The indices used in calculating the values of the angle of rotation are from published data. Values for the indices of quartz and calcite are standard and require no discussion. Published values for octahedrite and cassiterite show little variation. Rutile may vary in index, but the variations indicated in the literature are not enough to affect the calculated values of the angle of rotation significantly. The observed values given are in each case averages of five to seven readings of the angle of rotation. With the exception of the value for rutile in oil and for calcite in water, the observed values agree with the calculated values within the limits of error of measurement; the results of a considerable number of check readings indicate that angles of rotation can be measured from polarization figures with an accuracy of ± 0.3 degree. The discrepancies in the observed values for

TABLE I.

Mineral	n_1	n_2	Angles of rotation (in white light)					
			In air		In water ($n = 1.333$)		In oil ($n = 1.515$)	
			Calculated	Observed	Calculated	Observed	Calculated	Observed
Cassiterite (prism face)	1.996	2.093	1.75°	1.75°			4.47°	4.2°–4.7°
Rutile (prism face)	2.616	2.903	2.50°	2.6°			4.77°	4.3°
Octahedrite (prism face)	2.488	2.561	0.78°	0.75°			1.55°	1.5°
Calcite (cleavage)	1.566	1.658	3.5°	3.6°–3.8°	8.5°	9.3°*	76°	n. d.
Quartz (prism face)	1.544	1.553	0.37°	0.64°	1.3°	1.1°	7.54°	n. d.

* Measurement difficult owing to internal reflections.

rutile and calcite are probably due to internal reflections, which obscured the figures, particularly in oil or water immersion.

Cassiterite, rutile, and octahedrite are ore minerals in their own right, and rutile and octahedrite are not uncommon in certain ores of metals other than titanium. The data given in the table are therefore of interest from the standpoint of ore mineral identification. The angle of rotation for octahedrite in air is sufficiently different from the angles of rotation for cassiterite and rutile in air so that it could be distinguished from those two minerals on the basis of careful measurements. In oil, however, the difference is so great that even rough measurements would suffice for distinction. In oil immersion the differences are around 3°.

The use of the angles of rotation for identifying minerals has one serious limitation. Only the maximum value of the angle of rotation is characteristic for a mineral species. This value will be given only by a crystal face, cleavage,

or polished section parallel to the c-axis of a uniaxial mineral, or parallel to the optic axial plane of a biaxial mineral. In a polished surface containing a number of grains of an unknown mineral in random orientation, the maximum value must be obtained "statistically." The search is facilitated, however, by the fact that the grains giving the maximum value of the angle of rotation will likewise be those showing strongest anisotropism. For distinguishing between a pair of minerals such as rutile and octahedrite, moreover, it is not necessary that the maximum value of the angle of rotation be found. Let us suppose that a given unknown is determined as either rutile or octahedrite. Then if angles of rotation of a number of grains in oil immersion are all 1.5° or less, there can be little doubt that the mineral is octahedrite. If any of the grains, however, give values appreciably higher than 1.5°, the unknown cannot be octahedrite.

Berek [3] has pointed out that the indices of refraction corresponding to the two vibration directions of a polished section of a mineral may be calculated if the values of the angle of rotation for two immersion media of differing index of refraction are known. The most convenient formulae are the following, which are taken from Berek but are given here with certain changes in notation:

$$n_2^2 + n_2 \frac{(n_0'^2 - n_0''^2) \tan \psi \tan \psi'}{n_0' \tan \psi' - n_0'' \tan \psi} = n_0' n_0'' \frac{n_0'' \tan \psi' - n_0' \tan \psi}{n_0' \tan \psi' - n_0'' \tan \psi}, \quad (2a)$$

$$n_1^2 - n_1 \frac{(n_0'^2 - n_0''^2) \tan \psi \tan \psi'}{n_0' \tan \psi' - n_0'' \tan \psi} = n_0' n_0'' \frac{n_0'' \tan \psi' - n_0' \tan \psi}{n_0' \tan \psi' - n_0'' \tan \psi}. \quad (2b)$$

In these equations, n_1 and n_2 are, respectively, the lesser and the greater indices of refraction corresponding to the two vibration directions of the mineral section, n_0' is the immersion medium of lower index, n_0'' is the immersion medium of higher index, $\tan \psi$ is the angle of rotation in the immersion medium of lower index, and $\tan \psi'$ is the angle of rotation in the immersion medium of higher index.

Indices of refraction of a mineral section as determined by this method will only equal the true maximum and minimum indices of the mineral when the section observed has the proper crystallographic orientation; i.e., the section is parallel to the c-axis of a uniaxial mineral or to the optic axial plane of a biaxial mineral. Such a section will show maximum anisotropism and, as indicated in a preceding paragraph, will give the maximum value of the angle of rotation. If the mineral is uniaxial, each grain should give the true value of ω, but the value of ϵ could be approached only by making observations of ψ and ψ', and calculations of the indices, for a number of grains of various orientations. For biaxial minerals, pairs of values bracketing the β index will be obtained, but the values of α and γ must be determined statistically.

From a theoretical standpoint, the use of angles of rotation in different immersion media for determining indices of refraction would seem to be worth investigation. It is clear, of course, that the method is not likely to supersede standard immersion methods for determination of the indices of refraction.

[3] Berek, M., op. cit., pp. 33–34, 93–94.

These methods are well known, widely practiced, and conveniently applied to minerals lying within the range of ordinary immersion liquids. The value of the use of rotation angles would seem to lie in application of the method to anisotropic minerals of high index. Determination of the indices of refraction of these minerals by immersion methods has always been beset with difficulties.

The writer's work to date suggests, however, that there is a gap between theory and practice that must be bridged if the method is ever to gain wide use. Measurement of the angles of rotation by use of the analyzer is apparently accurate only to the nearest 0.3 degree. This is not sufficient for close calculation of the indices of refraction. Observations of rotation angles produced by a prism face of cassiterite serve as an example. An average reading of 1.75° was obtained for the angle of rotation in air. This agrees with the calculated value. For the angle of rotation in oil, however, four sets of seven readings each gave average values ranging from 4.2° to 4.7°. All four sets were made with equal care, hence the range of averages should be an adequate indication of the error of measurement. If 1.75° is used as the value of ψ, and 4.2° as the value of ψ', then from equations 2(a) and 2(b), $n_1 = 2.073$, $n_2 = 2.181$, and $n_2 - n_1 = .108$. These values may be compared with those given in Table I. It is evident that an error of 0.3° in measurement of either ψ or ψ' results in serious errors in the values of the indices as calculated from formulae (2a) and (2b). If the method is to be used for any but rough determinations, therefore, it is necessary that more accurate means of determining the angles of rotation than those available to the writer be devised. Measurement with the simple analyzer is not sufficiently precise.

A modification of the type of rotation compensator described by Turner, Benford, and McLean [4] might make it possible to measure angles of rotation more accurately. This compensator consists of a thin inclined quarterwave interference film of tin oxide cemented between two identical glass prisms. The compensator can be rotated through an arc of 90°, on an axis parallel to the tube axis of the microscope. The optics of this device are such that it acts as a "slow-motion" compensator with a step-down ratio of 5:1 to 8:1.[5] This gives the measurement of rotation much greater sensitivity than is possible with an analyzer. A modification of this device designed to be inserted in the tube of the microscope in place of the analyzer would be necessary.

The optics of reflection is considerably more complex for anisotropic absorbing ("opaque") minerals than for transparent minerals. The reflected vibrations are in general elliptically polarized. The incident plane-polarized rays in general undergo a rotation, and the reflected components of a given incident ray also differ in phase. The true angle of rotation cannot be measured by means of the analyzer alone; an apparent angle of rotation is measured instead. This angle is the azimuth of the major axis of the vibration ellipse of the reflected ray referred to the plane of vibration of the incident plane-

[4] Turner, A. F., Benford, J. R., and McLean, W. J., A polarized light compensator for opaque minerals: Econ. Geol., vol. 40, pp. 19–22, 1945.

[5] The ratio is given as 8:1 in the article quoted. The model in our laboratory, however, has a ratio averaging about 5:1.

polarized ray; it is a function of the rotation and also the phase difference introduced by reflection.

The apparent angles of rotation for anisotropic absorbing media are, like the angles of rotation for transparent media, functions of crystallographic orientation. Sections parallel to the *c*-axis of an absorbing uniaxial mineral will give the maximum and diagnostic value of the apparent angle of rotation. The maximum values for orthorhombic, monoclinic, and triclinic minerals will be given by sections or faces parallel to the plane bisecting the acute angle between the two conjugate pairs of Windungsachsen.[6] This plane is analogous to the optic axial plane in transparent biaxial minerals.

The factors determining the apparent angle of rotation produced by reflection from an anisotropic absorbing mineral include those that determine the angular rotation produced by reflection from an anisotropic transparent mineral. The apparent angle of rotation is therefore a function of the indices of refraction corresponding to the two principal vibration directions, the difference between these indices, and the index of the immersion medium. The apparent angle of rotation will therefore vary with the immersion medium. The angle is also a function, however, of the indices of absorption of the mineral section, and because the values of the indices of absorption will very rarely be known, the apparent angle of rotation will commonly not be calculable precisely. It can be approximated closely, however, for minerals of low absorption, by use of the equations given above for transparent minerals. This means ignoring the effect of absorption. According to Berek [7] however, the indices of absorption of most ore minerals are small, and the differences between the true angles of rotation and the apparent angles of rotation should be slight.

For practical purposes, the important thing is that the apparent angle of rotation is fully as diagnostic of a particular mineral species as the true angle of rotation, and the variations in the angle produced by varying the immersion medium should be fully as reliable for mineral identification as comparable values for transparent minerals. In addition, experience indicates that values for opaque minerals can be measured more accurately than those for transparent minerals, for the opaque minerals give no internal reflections and give sharper, more brilliant polarization figures. The brilliance is a function of reflectivity, which is higher for the opaque minerals.

In Table II, values of the apparent angles of rotation are given for 6 minerals, as measured from ordinary polished surfaces. The data indicate that the change in values of the angle of rotation produced by change in the immersion medium is not the same for all minerals. Marcasite shows the greatest percentage change, nearly a 200 percent increase. Miargyrite, on the other hand, shows only about a 30 percent increase. The other minerals show percentage increases that lie between these extremes. Though the data are limited, it seems evident that there will be pairs of minerals having apparent angles of rotation in air that are nearly the same but values in oil that are markedly different. Such minerals will be readily distinguishable by varying

[6] Berek, M., op. cit., p. 5; Schneiderhöhn and Ramdohr, op. cit., p. 134.
[7] Berek, M., op. cit., p. 8.

TABLE II.

Mineral[1]	n_1	n_2	Apparent angles of rotation[2]			
			In air		In oil ($n_{1.515}$)	
			Calculated	Observed	Calculated	Observed
Hematite[3] (section || c-axis)	2.797	3.042	1 9°	2.1°	3.4°	3.6°
Ilmenite (section || c-axis, intergrowth with hematite)				2.1°		4.5°
Ilmenite				2.8°		5.8°
Stibnite				4.3°		8.0°
Marcasite				0.6°		1.6°
Miargyrite				4.0°		5.2°
Pyrrhotite				2.0°		3.7°

[1] Except as noted, values given for each mineral were measured on a grain selected as showing maximum anisotropism.

[2] Values for ilmenite determined in white light. All others determined in red light.

[3] Values of n_2 and n_1 given are published values for $\lambda = 656$ mμ.

the immersion medium. Calculation of the apparent angles of rotation in red light for pyrargyrite and proustite, for example, gives the following values for true angles of rotation:

	In air	In oil ($n_{1.515}$)
Pyrargyrite	1.47°	2.65°
Proustite	2.16°	4.0°

As these two minerals have low absorption for red light, the true and apparent angles of rotation probably do not differ greatly. The values for hematite given in Table II are of interest in this connection. The calculated values of the true angles, ignoring absorption, are in close agreement with the values of the apparent angles of rotation obtained by actual measurement.

Values obtained for two types of ilmenite and given in Table II are likewise of much interest. The first set of values was given by a section parallel to the c-axis of a tabular crystal. This crystal is an intergrowth of ilmenite and hematite of the type discussed recently by Edwards.[8] Presumably the ilmenite still contains some hematite in solid solution. The values of the apparent angle of rotation are lower than those given by hematite-free ilmenite and approach those of hematite. It seems possible, therefore, that polarization figures may have some application to study of solid solution series.

Probably the most useful result of varying the immersion medium is the spreading of the range of apparent angles of rotation. Work to date suggests that angles for a number of opaque minerals lie within the range between 1 and 5 degrees. If oil immersion is used, however, the spread is nearly doubled. Thus in Table II, the spread of values for the minerals tested is only 3.7 degrees

[8] Edwards, A. B., Textures of the ore minerals: Australasian Inst. Min. Metallurg., Melbourne, pp. 58–60, 1947.

in air, whereas in oil the spread is 6.4 degrees. The need for great precision in measurement is correspondingly less.

The writer and L. H. Green [9] have shown that measurable dispersion of the apparent angle of rotation is shown by some opaque minerals, and this raises a question as to the effects of varying the immersion medium on dispersion formulas and as to the possible application of these effects to mineral identification. Investigation of this matter is under way but has not yet yielded sufficient data to warrant discussion.

CONCLUSIONS.

Preliminary studies suggest that changes in rotation properties obtained by varying the immersion medium can be used as an aid in the optical identification of ore minerals. The changes produced are different and diagnostic for various minerals, and some minerals not distinguishable on the basis of their rotation properties in air may be readily distinguishable by means of their rotation properties in water or oil. Limited application to the identification of transparent minerals is also suggested by preliminary results.

UNIVERSITY OF WISCONSIN,
MADISON, WISC.,
Sept. 26, 1950.

[9] Cameron, E. N., and Green, L. H., op. cit.

GROUND WATER IN ALLUVIAL DEPOSITS IN OKLAHOMA.[1]

STUART L. SCHOFF AND EDWIN W. REED.

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ABSTRACT.

Alluvium along main streams in Oklahoma has long been recognized as a generally dependable aquifer. Pumping tests made in recent years afford a means of comparing one area with another. They indicate coefficients of transmissibility on the order of 70,000 gallons per day per foot in the Arkansas River alluvium near Fort Gibson, and 60,000 in the North Canadian River alluvium near Oklahoma City and El Reno.

INTRODUCTION.

THE alluvium along the main streams of Oklahoma is considered an aquifer of major importance because relatively large yields may be obtained from it, generally much in excess of the yields possible from adjacent or subjacent bedrock. Although in some places the alluvium consists almost entirely of impervious clay or silt, in most places it includes layers of sand or buried channels of gravel that yield water freely. One of the larger yields reported from a single well in the State is 1,700 gallons per minute from a well at Ponca City [2] tapping ground water in the alluvium of the Arkansas River (Fig. 1).

Recharge to the alluvium received directly from precipitation is likely to be in larger amount than that received by the bedrock, especially where the upper part of the alluvium is sandy or gravelly. In addition, natural recharge may come to it as runoff from adjacent slopes and by infiltration from the streams. Furthermore, heavy pumping near streams may induce recharge by diverting part of the flow into the alluvium.

[1] Published with the permission of the Directors of the U. S. Geological Survey, the Oklahoma Geological Survey, and the U. S. Bureau of Reclamation. Presented at the El Paso meeting of the Society of Economic Geologists, November 1949.

[2] Schlesinger, Patrick, Oral communication, Ponca City Water Works.

Despite these favorable circumstances, ground water in the alluvium is not the perfect answer to all water-supply problems, for it is not all of desirable quality. In the alluvium of the Washita River the hardness of the ground water ranges from 300 to 600 parts per million, and even more locally, yet some towns use it because no other adequate source of water is within their reach. Salt springs discharge into Elm Fork, which is a tributary of the North Fork of the Red River, and the Cimarron River picks up salt and gypsum from the rock formations along its course. The ground water in the alluvium of these streams generally contains excessive amounts of chloride, yet the city of Stillwater found a small body of usable water in the alluvium of

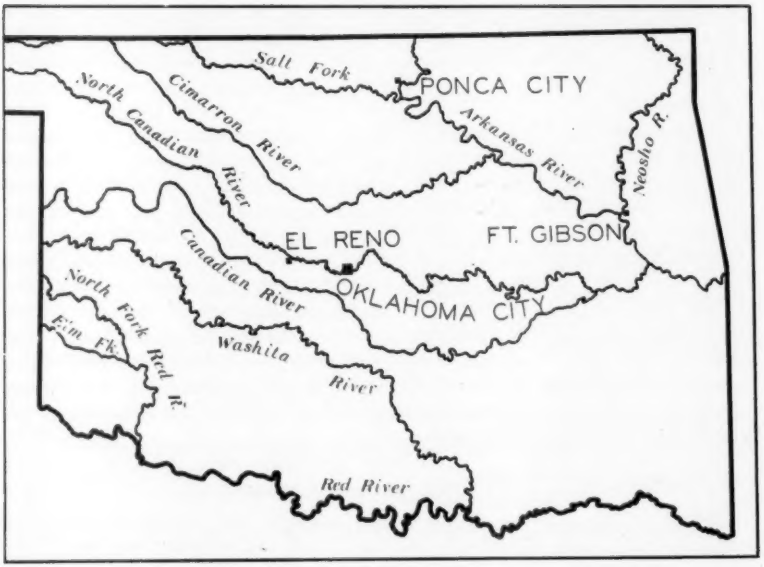

FIG. 1. Map showing some of the principal rivers of Oklahoma.

the Cimarron River because locally the runoff from adjacent higher areas recharges the alluvium with relatively fresh water. The disposal of oil-field brines into drainage courses has so contaminated both the surface water and ground water that in places it is unusable. The North Canadian River below Oklahoma City is an example of such contamination, although the alluvium of this stream yields hard but usable water to many towns and farms upstream.

STATUS OF HYDROLOGIC DATA.

Until recently, knowledge of the water-bearing properties of the alluvial deposits has been confined to reports on the performance of scattered wells,

such as the highly productive wells in the Arkansas River alluvium at Ponca City. When faced with a shortage of water during World War II, Oklahoma City pumped about 3.5 million gallons per day from the alluvium of the North Canadian River during a 3½-month period, but the crisis passed and pumping was discontinued before unmistakable long-term effects on the underground reservoir could appear.[3] El Reno has pumped about 2 million gallons per day from the alluvium of the same river for several years, apparently without serious effects. Of the Washita River alluvium, little is known except that wells yield from 150 to 300 gallons per minute.

Such reports are suggestive, but they do not permit ready comparison of the hydraulic properties of different aquifers, or of the same aquifer at different locations. The characteristics of an aquifer that determine its ability to yield water to wells are its thickness, which may be determined either from outcrop measurements or test drilling; its areal extent, determined by geologic mapping; and its coefficients of transmissibility (or its permeability) and storage, which are defined below.

The permeability of an aquifer is its ability to transmit water, and usually is expressed as the number of gallons of water per day that can move through each mile of the water-bearing bed (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient. In dealing with a single aquifer, it often is more convenient, and more representative of the aquifer as a whole, to use the coefficient of transmissibility, which is approximately the average permeability multiplied by the thickness of the aquifer. The coefficient of storage is the cubic feet of water discharged from each vertical column of the aquifer with a base 1 foot square as the water level falls 1 foot. These three hydraulic properties can be measured by means of controlled pumping tests. In paragraphs that follow, comparisons between aquifers and locations will be made by reference to the coefficients of transmissibility and storage.

PUMPING TEST AT EL RENO.

The first controlled pumping test made in Oklahoma by the U. S. Geological Survey was in 1942, in the alluvium of the North Canadian River near El Reno. A gravel-packed well about 200 feet from the channel was pumped for 24 hours at an average rate of 205 gallons per minute. The drawdown in the pumped well was 9 feet, and the specific capacity was 23 gallons per minute per foot of drawdown. The six observation wells were in a straight line, three on each side of the pumped well at distances of 25, 50, and 100 feet. The average coefficient of transmissibility based on this test is 59,250 gallons per day per foot, but a reliable coefficient of storage was not obtained. The computations yielded figures that increased for observation wells successively nearer the channel, from 0.01 to more than 1.0, indicating inflow of water from the river rather than normal drainage from an aquifer.

[3] Jacobsen, C. L., and Reed, E. W., Ground-water supplies in the Oklahoma City area, Okla.: Oklahoma Geol. Survey Mineral Rept. 20, 1949.

PUMPING TEST AT MUSTANG POWER PLANT.

The longest pumping test in alluvial sediments in Oklahoma was made in 1949 on the flood plain of the North Canadian River near Oklahoma City at the site of the Mustang Power Plant, which was being constructed for the Oklahoma Gas and Electric Co. A 10-inch gravel-packed well was drilled 69 feet deep, which penetrated about 40 feet of saturated alluvium. It had 9 feet of wrought iron screen, and was equipped with a turbine pump having a rated capacity of 700 gallons per minute, driven by a 50-horsepower electric motor. A 4-inch orifice was installed on the 6-inch discharge line, and five observation wells were drilled at distances of 50 to 500 feet from the pumped well, three of them in a line extending west from the pumped well, and two in a line extending south. During a 7-day test, the well yielded 500 gallons per minute with very little deviation, and the drawdown was 14.3 feet. The specific capacity, therefore, was 35 gallons per minute per foot of drawdown. Coefficients of transmissibility derived from the drawdown and recovery curves proved somewhat variable, but they are considered satisfactory if due allowance is made for the lithologic irregularities common to alluvial aquifers, and for the fact that the two lines of observation wells could not be in a single straight line. The average coefficient of transmissibility is about 60,000 gallons per day per foot, nearly the same as in the test at El Reno.

The coefficient of storage derived from the Mustang pumping test was only about 2 percent, which is far less than the 20 percent usually expected in sand and gravel aquifers. It is probable that the coefficient of storage of the entire aquifer was not actually determined. The figure (2 percent) is more representative of the upper fine-grained sand, which was dewatered, than of the lower coarse sand and gravel, which was not.

FORT GIBSON INVESTIGATION.

The most intensive investigation to date of ground water in alluvium was made near Fort Gibson in 1948 by the U. S. Geological Survey in cooperation with the U. S. Bureau of Reclamation. The objective of the investigation was to determine whether irrigation from wells would be practical in an area of 6,465 acres of Arkansas River bottom land just below the mouth of the Neosho (Grand) River (Fig. 2). The area is bounded on the north by the Neosho, on the west and south by the Arkansas, and on the east by a low bluff.

The water of the Arkansas River is highly mineralized and rather salty, but that of the Neosho is of good quality, although very hard. The Neosho enters the Arkansas from the east and its water usually does not become thoroughly mixed with that of the Arkansas for several miles below the confluence of the two rivers and well downstream from the area investigated. The water from the Neosho parallels the left bank of the Arkansas, adjacent to the Fort Gibson flood plain. Along the western side of the flood plain, therefore, river water drawn into the alluvium by heavy pumping should at first be more or less like Neosho River water. Only after protracted heavy pumping should it resemble the normal Arkansas River water. Hence under the seasonal pumping required for irrigation, little contamination of the underground

reservoir is likely to result from inflow of river water induced by pumping from wells near the river. The inflow, on the other hand, could prove of considerable value in sustaining the supply.

Test Drilling.—In the first phase of the investigation, 37 test holes were drilled by the hydraulic-rotary method, most of them penetrating 1 to 5 feet of the underlying bedrock. As revealed by these holes, the average thickness

FIG. 2. Map of the Fort Gibson area showing contours on the water table.

of the alluvium is 37.6 feet. Nearly everywhere in the area the alluvium consists of a bed of clay averaging about 16 feet in thickness underlain by a bed of sand and gravel averaging about 21 feet in thickness. Coarse gravel was encountered in a strip 0.25 to 0.5 mile wide flanking the Neosho River. Here boulders 5 inches across became lodged in the casing used in some of the test holes. Even larger boulders may have been pushed aside. Fine sand was

found along the east side of the area in a band extending about 0.5 mile westward from the bluff. The average thickness of saturated alluvium is about 24 feet.

Test Pumping.—Controlled pumping tests were made at three sites in the area (Fig. 2). For each test, an 8-inch well with 4-inch gravel walls was constructed, and six observation wells were drilled on a line passing through it. In the first two tests the spacing of the observation wells was 25, 50, and 150 feet from the pumped well. In the third test, the spacing was 10, 20, and 60 feet. In the first test a 14½-foot section of slotted 8-inch casing having about 1.3 square feet in openings was used to admit water to the well. Many slots became plugged with gravel, however, causing variations in the discharge and irregularities in the drawdown curve and making the results unreliable. For later tests, therefore, the area in openings was increased to about 1.7 square feet.

The first pumping test was made in the middle of the Fort Gibson flood plain, where the sand and gravel are of average coarseness but where a clay lens separates the water-bearing zone into an upper layer of fine-grained sand and a lower layer of coarse sand grading downward into gravel. The water table under static conditions was in the upper fine-grained sand. Large fluctuations of discharge in the pumped well and of water level in the observation wells, caused by clogging of the well screen, made this test unsatisfactory.

At the second site, which was 1 mile farther east, the well yielded 212 gallons per minute for 12 hours and 58 minutes, after which a heavy downpour stopped the engine driving the pump. As the drawdown was only 4.49 feet, the specific capacity of the well was 47.2 gallons per minute per foot of drawdown.

The third pumping test was made near the east bank of the Arkansas River. The well yielded 196.5 gallons per minute during 27 hours of pumping, with a drawdown of 11.93 feet, the specific capacity being 16.5 gallons per minute per foot of drawdown.

Interpretation of Pumping Tests.—The drawdown and recovery curves of the second and third pumping tests were analyzed by the Thiem formula and by the Theis formula using both the graphical method [4] and Jacob's modified method.[5] In all, 36 determinations of the coefficient of transmissibility were made, the average being 70,000 gallons per day per foot. This average is thought to be applicable to the area as a whole, due consideration being given to the thickness and character of the water-bearing alluvium as indicated by the test drilling.

The Theis formula was used to predict the effect on the water table of pumping for irrigation in the Fort Gibson area, taking first a unit of 40 acres. One well yielding 300 gallons per minute for 33 days would supply such an area with 1.1 acre-feet, which is the average water requirement of the locality as estimated by the Bureau of Reclamation. As the transmissibility of an

[4] Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 87–89, 95–96, 1942.

[5] Jacob, C. E., Notes on determining permeability by pumping tests under water-table conditions: U. S. Geol. Survey mimeographed report, June, 1944.

aquifer diminishes under pumping because of reduction in thickness of the zone of saturation occasioned by drawdown in the pumping well or wells, two coefficients of transmissibility were used in the calculations: 70,000 gallons per day per foot, as determined in the pumping tests, and 35,000 gallons per day per foot, representing an extreme reduction in transmissibility not likely to occur even in unusually dry seasons. Curves showing the drawdown to be expected at different distances from a well being pumped at a rate of 300 gallons per minute for 33 days, based on both the above coefficients, are shown in Figure 3.

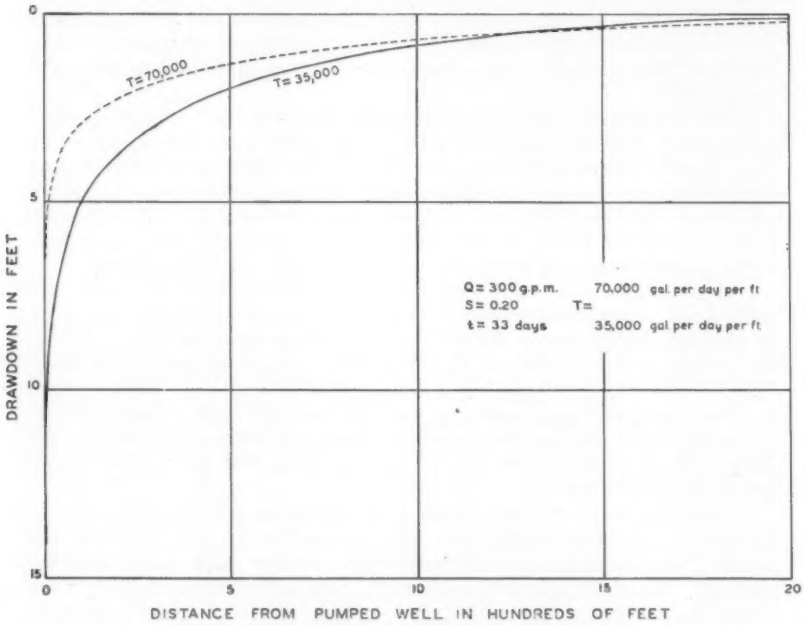

FIG. 3. Drawdown at different distances from well pumping 300 gallons per minute for 33 days, assuming two coefficients of transmissibility.

If it is assumed that full development of irrigation in the Fort Gibson flood plain will mean one well in the middle of each 40-acre tract pumping 300 gallons per minute, and all wells pumping simultaneously and continuously for 33 days, the extra drawdown in any one well caused by pumping in all the others will not exceed 4 feet. It is obvious, of course, that this ideal condition will not be met—that wells will not be uniformly spaced or equal in yield, or operated simultaneously—but it is evident that with reasonable distribution of wells and of pumping load, serious lowering of the water level in any one well due to pumping in others is unlikely.

Ground-Water Storage.—As the pumping tests were too short to yield reliable figures on the coefficient of storage, a coefficient of 20 percent was assumed. From this it was calculated that 31,000 acre-feet of water is stored in the alluvium—enough for eight seasons of irrigation at the rate of consumption anticipated by the Bureau of Reclamation.

Ground-Water Recharge.—Recharge, which is the addition of water to the aquifer, may be derived in the Fort Gibson area from precipitation directly on the surface of the flood plain, from the surface runoff coming from adjacent uplands, from the underflow coming from the underlying bedrock, and from the influent seepage from the Neosho and Arkansas Rivers.

An accurate estimate of the recharge derived from precipitation would require several years of observation of water levels in many wells distributed widely over the area. This is an enterprise beyond the scope of the investigation conducted at Fort Gibson, but an estimate of the possibilities can be made. According to the U. S.Weather Bureau, the precipitation averages 41.46 inches per year at Muskogee, which is about 3 miles west of the Fort Gibson area. If 17.3 percent of this precipitation— a not unreasonable fraction—were to become ground water, the requirements of the area for irrigation water would be met. Additional recharge from the other indicated sources should bring the total annual recharge safely above the estimated annual demand for irrigation water. From a study of the slope of the water table it is estimated that much more than this amount was discharged from the alluvium into the river over a period of several months during the summer of 1948.

CONCLUSIONS.

Although each pumping test is evidence of conditions only in the area immediately surrounding the pumped well, and the pumping tests thus far performed in the alluvium along major streams of Oklahoma represent mere pin points in comparison with the total area of alluvium, the results indicate that moderately large sustained yields may be expected generally. Tests in the alluvium of the North Canadian River near Oklahoma City and El Reno have yielded surprisingly similar coefficients of transmissibility, and these have been only about 14 percent lower than in the alluvium of the Arkansas River at Fort Gibson.

U. S. GEOLOGICAL SURVEY,
NORMAN, OKLA.,
Sept. 18, 1950.

SCIENTIFIC COMMUNICATIONS

AEROMAGNETIC IRON ORE DISCOVERIES IN MINNESOTA.

Discovery of a previously unsuspected extension of the rich Vermilion range iron formation in northern St. Louis county was reported recently by Dr. George M. Schwartz, director of the Minnesota Geological Survey and professor of geology at the University of Minnesota.

Aeromagnetic maps released recently by the United States Geological Survey indicate that the hematite producing Vermilion range curves southeastward from the Tower-Soudan area into the roadless wilderness between Embarrass and Bear Head Lake. Vermilion range hematite is a high-grade iron ore. This new aeromagnetic picture of the Vermilion range is believed by Dr. Schwartz to justify considerable exploration and drilling for possible iron ore deposits in an area of about 20 square miles southeast of Soudan. The area is included in Township 61 North, 14 West, he explained, and is covered by glacial drift to a depth of from 50 to 100 feet. According to available geologic records, no previous exploration for iron ore formations has been carried on in this area.

Indications of the Vermilion range extension were found on one of three maps released recently by the United States Geological Survey in connection with the coöperative aerial search by the United States Geological Survey and the Minnesota Geological Survey for potential new iron formations which has been underway since 1947 in a 30,000-square-mile area in northern Minnesota. The three new maps cover an area of approximately 1,800 square miles in eastern St. Louis county in which lie most of the Vermilion range and the eastern portion of the Mesabi iron range. Aeromagnetic maps covering approximately 25,000 square miles of the 30,000-square-mile area of the aerial "treasure hunt" have now been made available to the public. Earlier maps resulting from the survey showed potential new iron formations in Hubbard, Cass, Becker, Otter Tail, Itasca and Aitkin counties. Mining engineers are now exploring some of these promising areas.

The maps recently released also indicate, according to Dr. Schwartz, a large igneous intrusive to the south of the eastern end of the Mesabi range, which "baked" the iron-bearing rock formation of the Mesabi and evidently intensified the magnetic attraction in that area by converting the iron formation to magnetite, which is the principal iron-bearing mineral of taconite rock. The aeromagnetic readings show that the earth's magnetic attraction in the vicinity of Babbitt at the eastern end of the Mesabi range is about three times that found in the Hibbing area farther west. It is at the eastern end of the range that the Reserve Mining Company plans to mine taconite which will be concentrated at Beaver Bay on Lake Superior before shipment to eastern steel mills.

The purpose of the coöperative survey was to determine the major magnetic trends associated with known deposits of iron ore in the state and thus to ascertain possible extensions of those deposits and to indicate new areas that may be favorable for further ore exploration.

The necessity for aerial magnetic work arises from the problem of the thick glacial drift over much of northern Minnesota. Magnetic work on the ground has been carried on for a long time in the state, but the process is slow, and consequently, only selected areas have been covered. No one person or group has access to more than a fraction of the data thus compiled.

Maps resulting from the survey and released to date are on file for public inspection at three places in the state: 1. The Minnesota Geological Survey office in Pillsbury Hall on the University of Minnesota campus; 2. The office of the U. S. Bureau of Mines, Federal Building, Duluth; and 3. The office of the Division of Lands and Minerals, Hibbing.

DISCUSSIONS

GEOLOGY OF THE FISSIONABLE MATERIALS.

Sir: In a recent interesting paper [1] George W. Bain has given a general statement of uranium and thorium ore resources, types, occurrence, and geological associations of the fissionable materials, a survey as complete as possible of the more important uranium and thorium occurrences of the world.

The general conclusion which the author has reached is that the primary deposits of fissionable materials have wide geographical distribution and are confined to metallographic provinces, and at the same time the distribution appears to be related to original differences in components of the earth. One other outstanding feature is that the principal uranium deposits are on the periphery of shields or in very large massifs, distributed as a rule in crystalline rocks, whereas the center of shields is generally free from fissionable materials. The primary mineralization is in part concentrated into lodes, but there is diffuse mineralization within pegmatites all over the world.

The transmutation theory [2] may be able to explain such occurrences, and Bateman,[3] and other authors, on the basis of metallogenetic provinces, have raised the question of whether some elements may undergo in one way or another some atomic change in the depths of the earth that might build up one or another of the metallic atoms. The principal agent of such changes would be pressure developed within the magma, pressure that may reach a million atmospheres or more.[4] The conclusion reached by Bain that uranium and thorium appear related to particular elements of the earth and to well-defined localities seems to me logical; at the same time transmutation appears to be a necessary genetic mechanism to explain not only the occurrences of fissionable materials, but also those of other metals.

The writer considers it important that a thorough study be made in order to find out whether primary metallic deposits are generally related to orogenic forces, and the possibility that the transmutation mechanism here considered may be in one way or another a starting phase in the building up of mineral deposits is a thought that should be seriously considered.

CORNELIO L. SAGUI.

AVIGNON, FRANCE,
Dec. 4, 1950.

[1] Bain, George W., Geology of the fissionable materials: ECON. GEOL., vol. 45, pp. 273–323, 1950.

[2] Sagui, C. L., La métallogenèse magmatique: Publ. del Inst. de Fisiogr. y Geol., Univ. del Litoral, no. III, Rosario, Argentina, 1938.

[3] Bateman, Alan M., Economic Mineral Deposits, John Wiley & Sons, New York, 1942.

[4] Sagui, C. L., op. cit.

REVIEWS

Geochemistry. By KALERVO RANKAMA AND TH. G. SAHAMA. Pp. 912; figs. 51; tbls. 218. University of Chicago Press, Chicago, Ill., 1950. Price, $15.00.

This excellent volume will find a place on the reference shelf of every intensive student of deposits of ores and non-metallic minerals, of petrology and of mineralogy and will doubtless serve as the foundation for courses in geochemistry, theoretical and applied. The authors are to be congratulated on their conscientious and unprejudiced, if somewhat encyclopedic compilation of so much diverse material. This work has been especially needed not on its own account alone but also since there has been no revision of F. W. Clarke's monumental "Data of Geochemistry" since 1924, and the death of the two great Russian geochemists, Vermadsky and Fersman in the same year (1945), has precluded the possibility of help from their fluent and stimulating pens. The appearance of this new work points up again the importance to all basic sciences of compendial volumes such as this, as distinct from monographs designed to advance specific theses, which these days need no defense. A debt is owing the publisher for making the work available to us.

The contrast between this book and Clarke's volume is to be seen from the definition of geochemistry with which the volume by the two Finnish scientists virtually begins. For Clarke says, in so many words, "Each rock may be regarded . . . as a chemical system" in which changes result from disturbances of equilibrium and, "The study of these changes is the province of geochemistry." Drs. Rankama and Sahama, on the other hand, say expressly that the geochemist finds that "his problems are those of a chemist or a physical chemist" whose objectives differ from those of the chemical geologist, who, as described by them, focusses chemistry on the problems of geology. In consequence of these contrasting attitudes, Clarke, though a chemist in background, wrote a book that was a summary of geologic processes the dynamics of which were chemical: he was content with a description of the elements extending from page 12 to page 44, whereas for these more recent scholars the entire second part of the book—some 376 pages—scarcely suffices to define the elements.

Yet this apparent contrast is, in a sense, deceiving. For under each element, despite the conscientious descriptions of its occurrence on the earth, its general behavior, its more common mineral combinations, and its relative abundance, there is always at least a terse consideration of its behavior in magmas (of particular interest to petrogenists) and its role in more surficial geologic processes (sedimentation, weathering, and the like). Thus the geological reader, if he happens to be concerned with ore deposits, finds much food for thought in such sections as those entitled "Cycle of copper," "Cycle of manganese," and the like, even though the expected headings of "Secondary enrichment" and "Residual concentration" do not appear in the very extensive subject index.

Part I of the book is, in fact, a treatment of the chemical processes of geology, as a quick perusal of some of the chapter headings, such as "Geochemistry of the Biosphere," "Outlines of the Geochemical Evolution of the Earth," and others, amply demonstrates.

Throughout the work little strains of academic overtures appear (as in the threatened refusal to consider meteorites in a book on the chemistry of the earth, page 17), fortunately usually manfully suppressed (as in the ensuing excellent sum-

mary of the composition of meteorites, pages 17–31)! The punctilio with which each element is treated according to a rigorous outline smacks of the same characteristic, yet adds value because little that is essential for each is omitted under that plan. There is a tendency to introduce unnecessarily awkward words (e.g., "magmagenic" and "sedimentogenic" on page 32, and "biophile" on page 322) but this can be readily forgiven when a relatively new aspect of a science is being discussed.

Perhaps the thing that will receive the most appreciation from all who use this book will be the up-to-dateness of the treatment. It is manifestly impossible to deal at great length with the myriad subjects here necessarily touched upon. To mention only a few, the authors present thoughtful summaries of the present-day viewpoints regarding cosmogeny, the carbon dioxide cycle, Berl's ideas regarding the origin of petroleum, the many effects of variations in pH on geologic processes, indigenous criteria for the temperature of formation of certain sulphides, the nature of diagenesis, granitization, and the processes involved in the sedimentary origin of iron ores. For the practising economic geologist, especially, prevented from taking "refresher" courses (even if they were available) by the pressure of time and perhaps as well by the sudden emergence in the geochemical literature of chemical and physical concepts not even hinted at in his student days, such a book is a joy and a bright light cast alternately into the many crannies of a dark room. Particularly refreshing is the almost invariably completely unprejudiced attitude of mind with which debatable subjects are approached, thus offering the reader a fresh yet trustworthy, balanced viewpoint.

The tables are numerous, cleverly numbered to correspond with the chapters, and well put together. Not the least of the items for which the reader will be thankful are the clear, legible type on a paper thick enough to avoid confusion with the text on the reverse of the page, yet light enough so that the many pages, necessitated, perforce, by the extent of the subject, still do not make the book hopelessly bulky or awkward.

CHAS. H. BEHRE, JR.

COLUMBIA UNIVERSITY,
NEW YORK, N. Y.,
Oct. 12, 1950.

Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes. By M. JUUL HVORSLEV. Pp. 521; figs. 379; tbls. 14. The Engineering Foundation, New York, 1949. Price, $6.00.

This excellent work which is prepared primarily for the civil engineer should also be of interest and value to the engineering and economic geologist.

It was prepared as a research project of the Committee on Sampling and Testing Soil Mechanics and Foundations, Division American Society of Civil Engineers, and sponsored by the Engineering Foundation, Graduate School of Engineering, Harvard University and Waterways Experiment Station, U. S. Corps of Army Engineers.

The work which covers 500 pages is a valuable reference work on subsurface exploration and sampling of soils and rocks.

The book consists of two parts. Part I is a detailed discussion of the requirements, general procedures and various methods of subsurface exploration and sampling. Part II discusses the details of equipment and methods used in obtaining samples of subsurface materials as well as the preservation and handling of these samples. This part also gives a review of the methods and equipment used in ocean

bottom exploration and in the search for oil and minerals. Numerous illustrations add to the value of the work.

The book also contains a valuable bibliography containing references to both American and foreign literature.

H. RIES.

CORNELL UNIVERSITY,
ITHACA, N. Y.,
November 6, 1950.

The Science of Petroleum—Crude Oils—Chemical and Physical Properties. BENJAMIN T. BROOKS AND A. E. DUNSTAN, Editors. Pp. 200; figs. 101; tbls. 89. Oxford University Press, New York and London, 1950. Price, $11.00.

This is the first part of Volume 5 of the internationally known series of The Science of Petroleum, of which Volume 1 appeared in 1938 and dealt with the Origin and Production. Volumes 2 and 3 (1938) dealt with the Chemical and Physical Principles of Refining. Volume 4 (1938) dealt with Utilization, Detonation and Combustion, and Bituminous Materials and Their Products.

The present volume deals in Section 1 with Crude Oils as follows: United States, by H. M. Smith; Venezuela, by Gulf Oil Company; Saudi Arabia, by Arabian-American Oil Co.; Bahrein Island, by J. R. Keith; Middle East, by D. A. Howes and L. C. Strang; Evaluation of Crude Oils and Oil Stocks, by W. L. Nelson; and Economic Developments in the Petroleum Industry, by O. Tokayer. Section 2 covers the Chemical and Physical Properties of Petroleum Hydrocarbons in 9 papers by 8 authors, as follows: Hydrocarbons in Petroleum, by A. N. Sachanen; Chemistry of Paraffin Hydrocarbons, by J. Habeshaw; Chemistry of Naphthene Hydrocarbons, and Chemistry of Aromatic Hydrocarbons, by W. J. Oldham; Chemistry of Olefine and Diolefine Hydrocarbons, by F. A. Fidler; Mechanism of Organic Reactions, by F. C. Whitmore and N. C. Cook; Fractionation, Analysis, and Isolation of Hydrocarbons in Petroleum, by B. J. Mair and F. D. Rossini; Chemical Thermodynamic Properties of Hydrocarbons, by F. D. Rossini; and High-Pressure Vapour-Liquid Equilibria in Cycling Operations, by D. L. Katz and M. J. Rzasa.

This volume is of the same size and the same fine standards of printing and illustrations as the predecessor volumes. It is the last word on the Chemical and Physical Properties and a survey of world crudes. It is a fitting companion to the other four volumes.

Conservation of Natural Resources. Edited by GUY-HAROLD SMITH. Pp. 552; figs. 176; tbls. 42. John Wiley & Sons, Inc., New York, and Chapman & Hall, London, 1950. Price, $6.00.

This finely printed addition to the subject of conservation is the work of 20 authors who are specialists in different resources. The book begins with a chapter on a review of the history of conservation in the United States by A. C. Wright, followed by one on "The Public Domain and Its Disposal" by S. S. Visher, then follow 8 parts dealing with various phases of resources. This volume is a reorganization and rewriting, with nine new authors, of *Our National Resources and Their Conservation* first published in 1936 and revised in 1939. The various chapters and the authors of the present volume are: The Great Soil Groups and Their Utilization, by L. A. Wolfanger; Soil Conservation, by W. A. Rockie; Tree Crops, by J. R. Smith; American Irrigation, by R. H. Brown; Grassland Resources, by H. C. Hanson and W. C. Whitman; Reclamation of Wet and Overflow Lands, by

G. J. Miller; The Agricultural Prospect, by G. H. Smith; Our Forest Resources, by O. D. Diller; The Practice of Forest Conservation, by O. D. Diller; Water Supply for Domestic and Industrial Uses, by J. H. Garland; Water Power and Its Conservation, by G. H. Smith; Our Waterways and Their Utilization, by E. J. Foscue; Floods and Flood Control, by G. H. Smith; Conservation in the Mineral Kingdom, by W. M. Myers; The Mineral Fuels, by E. W. Miller; Conservation of Wildlife, by C. A. Dambach; Fisheries for the Future, by H. H. Martin; Recreational Resources, by E. C. Prophet; The Conservation of Man, by E. Huntington; State and Local Planning, by L. Durand, Jr.; National Planning and the Conservation of Resources, by G. H. Smith.

Part V, on Conservation in the Mineral Kingdom, and The Mineral Fuels, give comprehensive pictures of these resources. The first one, by W. M. Myers, starts with an interesting chapter on the historical development of the mineral industries, tracing it from primitive man, through the Colonial period and the industrial revolution to 1900, then their development since that time. Considerable space is devoted to reserves and the coverage of the other phases of conservation is broad and well treated. Unfortunately most of the statistical and tabular data are no later than 1945, 1946, or 1947, perhaps because there may have been slowness in completion and in publication.

The various chapters give the basic geographical and conservational features of each resource, their conservation practices, their extent, distribution, uses in regional and national development, and their bearing on national security. The up-to-date material and concepts by so many recognized authorities makes this book the leader in conservation of natural resources.

BOOKS RECEIVED.

CHARLES H. SMITH.

U. S. Geological Survey—Washington, D. C., 1949–1950.

Bull. 962-B. Antimony Deposits of El Antimonio District, Sonora, Mexico. DONALD E. WHITE AND REINALDO GUIZA. Pp. 38; pls. 13; figs. 2. *Veins of quartz, oxides of antimony and some gold and silver, filling thrust faults. Ore is generally localized in the flatter-dipping parts of the veins and at or below the intersections of the main veins with pre-mineral faults. Veins and placers are mined. Indicated reserves are 46,000 to 73,000 metric tons containing 2,950 to 8,850 metric tons of antimony.*

Bull. 976-B. Geophysical Abstracts 141, April–June 1950. MARY C. RABBITT AND S. T. VESSELOWSKY. Pp. 64. *Nos. 11908 to 12125.*

Water-Supply Papers.

1068. Wells and Water Levels in Principal Ground-Water Basins in Santa Barbara County, California. G. A. LA ROCQUE, JR., AND OTHERS. Pp. 457; pls. 7; figs. 8.

1072. Water Levels and Artesian Pressure in Observation Wells in the United States in 1946. Pt. 2. Southeastern States. UNDER THE DIRECTION OF C. G. PAULSEN. Pp. 272; figs. 17.

1081, 1085, 1093. Surface Water Supply of the United States 1947. UNDER THE DIRECTION OF C. G. PAULSEN. **Pt. 1. North Atlantic Slope Basins.** Pp. 682; fig. 1. **Pt. 5. Hudson Bay and Upper Mississippi River Basin.** Pp. 479; fig. 1. **Pt. 13. Snake River Basin.** Pp. 269; fig. 1.

1114, 1117, 1119, 1120, 1121. Surface Water Supply of the United States 1948. UNDER THE DIRECTION OF C. G. PAULSEN. **Pt. 4. St. Lawrence River Basin.** Pp. 296; fig. 1. **Pt. 7. Lower Mississippi River Basin.** Pp. 418; fig. 1. **Pt. 9. Colorado River Basin.** Pp. 421; figs. 2. **Pt. 10. The Great Basin.** Pp. 216; fig. 1. **Pt. 11. Pacific Slope Basins in California.** Pp. 449; fig. 1.

U. S. Bureau of Mines—Washington, D. C., 1950.

Minerals Yearbook 1948. UNDER THE DIRECTION OF E. W. PEHRSON; ALLAN F. MATTHEWS, EDITOR. Pp. 1652. U. S. Government Printing Office. Price, $4.25. *This volume reviews the production, distribution, and consumption of all mineral commodities, including fuels. In this edition the growing importance of foreign minerals to the Nation's domestic economy in peace and war has been recognized. Commodity reviews on both metals and nonmetals, as well as State reviews, have been written and edited by specialists in each field.*

Rept. Inv. 4722. Investigation of the White Zinc-Lead Deposit, Lafayette County, Wis. W. A. GROSH. Pp. 5; figs. 2. *Part of the Upper Mississippi lead-zinc field. 678 feet of drilling done, which indicate low lead-zinc values.*

Rept. Inv. 4727. Physical Properties of Mine Rock, Pt. II. S. L. WINDES. Pp. 37; figs. 7; tbls. 9. *Presents physical and petrographic properties of approximately 60 types of rock. Selection, preparation, and testing of samples described and results tabulated.*

Inf. Circ. 7582. Energy Uses and Supplies, 1939, 1947, 1965. HAROLD J. BARNETT. Pp. 53; tbls. 28; charts 6. *A summary of preliminary results of an exploratory study of energy uses and supplies in the U. S., including a preliminary projection for 1965.*

Whiteware Raw Material Resources of Japan. DONALD E. LEE AND HIDESHIRO HASEGAWA. Pp. 61; figs. 19; tbls. 57. General Headquarters, Supreme Commander for Allied Powers, Natural Resources Section Rept. 135. *Considers Japan's resources of china clay, quartz, felspar, and china stone. These are one of the country's most important exports. Areal descriptions, mining methods, costs, and reserves described.*

Analytical Data on Reference Clay Minerals. PAUL F. KERR, P. K. HAMILTON, R. J. PILL, G. V. WHEELER, DONALD R. LEWIS, W. BURKHARDT, DUANE RENO, GARVIN L. TAYLOR, R. C. MIELENZ, M. E. KING, N. C. SCHIELTZ, AND LA HABRA LABORATORY. Am. Petrol. Inst. Project 49, Clay Mineral Standards, Prel. Rept. 7. Columbia Univ., New York, July 1950. Pp. 160; figs. 28; tbls. 34; pl. 1. *This publication is one of a series on the clay minerals issued by the A.P.I. The report includes information on X-ray diffraction measurements, chemical analyses, pH data, differential thermal analyses, optical properties, semi-quantitative spectrographic analyses, base-exchange data, magnetic susceptibility, particle size determinations, and staining tests.*

Geological Map of South America. South American Geological Map Committee, Geol. Soc. America, A. I. LEVORSEN, CHAIRMAN; G. W. STOSE, EDITOR. New York, 1950. *Two sections, in color; scale, 1:5,000,000.*

Geologic-Tectonic Map of the United States of Venezuela (except the Territory of Amazonas and part of the State of Bolivar). COMPILED BY W. H. BUCHER. Geol. Soc. America, New York, 1950. *In color, scale, 1:1,000,000.*

Geology and Oil-Shale Resources of the Eastern Part of the Piceance Creek Basin, Rio Blanco and Garfield Counties, Colorado. D. C. DUNCAN AND CARL BELSER. U. S. Geol. Survey Oil and Gas Inv. Map OM 119, Washington, D. C., 1950. *Character and relationship of the oil shales in 4 subsurface sections and in a surface section.*

Summary of Operations—California Oil Fields. Pp. 167; numerous plates. California Dept. Nat. Res., 35th Annual Rept., Vol. 35, no. 2, San Francisco, July–Dec. 1949. *Descriptions of the Placerita and San Ardo oil fields; statistics.*

Illinois Geological Survey—Urbana, 1950.

Bull. 75. Groundwater in the Peoria Region. Pt. 1. Geology. LELAND HORBERG. **Pt. 2. Hydrology.** MAX SUTER. **Pt. 3. Chemistry.** T. E. LARSON. Pp. 128; pls. 4; figs. 53; tbls. 10. *Summary of geologic conditions controlling groundwater occurrence in Peoria region and attempts to evaluate these conditions and indicate areas favorable for development of additional groundwater supplies.*

Circ. 166. Mineral Resource Research and Activities of the State Geological Survey, 1948–1949. M. M. LEIGHTON. Pp. 20; numerous photos.

Illinois Petroleum 62. Oil and Gas Development in Illinois in 1949. ALFRED H. BELL AND VIRGINIA KLINE. Pp. 41. *Statistics.*

Kansas Geological Survey—Kansas University Publications, Lawrence, 1950.

Bull. 86, Pt. 3. The Cheyenne Sandstone of Barber, Comanche, and Kiowa Counties, Kansas, as Raw Material for Glass Manufacture. EARL K. NIXON, RUSSELL T. RUNNELS, AND ROBERT O. KULSTAD. Pp. 43; figs. 4; pls. 2. *Studies show there are reserves, adequate for commercial operation, of sands that are amenable to beneficiation and meet the required standards of chemical composition.*

Bull. 86, Pt. 4. Silica Sand from South-Central Kansas for Foundry Use. KENNETH E. ROSE. Pp. 19; figs. 2. *Cheyenne sandstone can be a satisfactory source of silica sand for making synthetic molding sand or cores. The market for foundries alone is not now of sufficient size to justify any large-scale development.*

Bull. 86, Pt. 5. Origin and Environment of the Tonganoxie Sandstone in Northeastern Kansas. THOMAS W. LINS. Pp. 35; figs. 3; pl. 1. *Four types of deposits in the Tonganoxie sandstone are described and interpreted.*

Missouri Geological Survey—Rolla, 1950.

Inf. Circ. 6. The Mineral Industry of Missouri in 1948. OTTEY M. BISHOP. Pp. 21; tbl. 1. *Individual descriptions of minerals produced.*

Rept. Inv. 12. A Stratigraphic Study of the Upper Marmaton and Lowermost Pleasanton Groups, Pennsylvanian, of Missouri. L. M. CLINE AND FRANK C. GREENE. Pp. 74; fig. 1; tbl. 1; charts 7. *Results of stratigraphic and faunal studies. 24 composite columnar sections presented. Discussion centers around correlation of the Coal City, Lenapah, and Exline limestones, the Hepler and "Wayside" sandstones, and the stratigraphic position of the Desmoinesian-Missourian boundary in Missouri.*

Guidebook to the Geology of the Pennsylvania Turnpike: Carlisle to Irwin. ARTHUR B. CLEAVES AND ROBERT C. STEPHENSON. Pp. 72; figs. 7; pls. 28; tbls. 3. Pennsylvania Topographic and Geologic Survey Bull. G-24, Harrisburg, 1949. *A concise description of the physiography, and the general, engineering, and economic geology is given, followed by a geologic itinerary and strip maps.*

The Australian Mineral Industry—Economic Notes and Statistics, Vol. 3, No. 1. Pp. 40. Australia Bur. Min. Res., Geol., and Geophysics, Melbourne, 1950. *Includes a section on Australian lead supplies.*

The Geology and Mineral Resources of the Neighbourhood of Chegar, Perah and Merapoh, Pahang. J. A. RICHARDSON. Pp. 162; figs. 20; pls. 3; 2 colored maps, scale, 1″ = 1 mi. Malaya Geological Survey Mem. 4, Kuala Lumpur, 1950. Price, $6.00. *A detailed description of the calcareous and arenaceous rocks, volcanics, granitic to dolerite intrusives, superficial deposits, detrital minerals, geomorphological evolution and structure. The economic geology of the lode and alluvial gold deposits, as well as other mineral resources, is described at length.*

The Geology of the Country around Gwelo. R. TYNDALE-BISCOE. Pp. 145; pls. 18; figs. 10. Southern Rhodesia Geol. Survey Bull. 39, 1949. Price, 6s, 6d. *A systematic description of one of the Rhodesian gold belts. Areal geology outlined and individual properties described. Chromite is also of importance. Colored geological map, scale, 1:100,000.*

SOCIETY OF ECONOMIC GEOLOGISTS

JOINT TECHNICAL SESSIONS OF THE SOCIETY OF ECONOMIC GEOLOGISTS WITH THE MINING, GEOLOGY AND GEOPHYSICS DIVISION, THE COAL DIVISION, AND THE INDUSTRIAL MINERALS DIVISION OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS.

GEOLOGY SUBDIVISION.

Monday, February 19.

9:00 A.M. Ivory Room (J) Jefferson Hotel

Joint session with Industrial Minerals Division and Society of Economic Geologists.

Symposium organized by A. F. Frederickson on "Diaspore and other Hydroxides."

E. C. Harder and A. F. Frederickson, Associate Chairmen.

"Examples of Bauxite Deposits Illustrating Variations in Origin"	E. C. Harder Aluminum Secretariat Ltd.
"The Genetic Significance of Mineralogy"	A. F. Frederickson Washington University
"The Composition of Argillaceous Rocks in Relation to their Conditions of Genesis"	G. Milliott University of Nancy (Read by Haydn Murray University of Illinois)
"Genesis of Clay Minerals"	E. Hauser Institute of Technology Cambridge, Mass.
"New Clay Mineral Evidence Concerning the Diagnosis of Some Missouri Fireclays"	J. F. Burst Shell Oil Company
"The Structure of Hydrous Aluminum Oxides and Hydroxides"	W. O. Milligan and J. L. McAtee Rice Institute of Technology
"Changes in Clay Mineral Character with Distance of Transportation"	R. A. Rowland Shell Oil Company

GEOLOGY SUBDIVISION.

Monday, February 19.

2:30 P.M. Tuttle Memorial Room De Soto Hotel?

Joint session with Industrial Minerals Division and Society of Economic Geologists.

Symposium organized by A. F. Frederickson on "Diaspore and other Hydroxides."

E. C. Harder and A. F. Frederickson, Associate Chairmen.

"Studies in the System Al_2O_3–SiO_2–H_2O"	R. Roy and E. F. Osborne Penn State College

"Random Observations on the Origin of Missouri Diaspore"	W. D. Keller University of Missouri
"The Kisameet Bay Clay Deposit"	E. Hauser Institute of Technology Cambridge, Mass.
"Interrelationships between Structure and Genesis in the Kaolinite Group"	T. F. Bates Penn State College
"Genesis and Morphology of the Alumina-Rich Laterite Clays"	G. D. Sherman University of Hawaii
"Alteration of Phosphatic Limestone to Montmorillonite Clay"	F. R. Hunter International Minerals and Chemical Corporation
"Distribution and Occurrence of the Mercer Fireclay of North-Central Pennsylvania"	R. C. Bolger Washington University and J. H. Weitz Lehigh University

GEOLOGY SUBDIVISION.

Monday, February 19.

2:30 P.M. Ivory Room Jefferson Hotel

Joint Session with Mining Subdivision.

Symposium Organized by G. B. Clark on "Geology and the Choice of Mining Methods."

G. B. Clark and J. D. Forrester, Associate Chairmen.

"The Relation of Geology to Mining Methods at Climax"	M. S. Walker Climax Molybdenum Co.
"Structural Geology as the Setting for Mining Operations"	Edward Wisser Univ. of California
"Application of Geology to Mining at Giant Yellowknife"	J. D. Bateman Giant Yellowknife Mines, Ltd.
"Design of Underground Mines"	R. S. Loofbourow E. J. Longyear Co.

GEOLOGY SUBDIVISION.

Monday, February 19.

2:30 P.M. Rooms 102–104–106 Jefferson Hotel

Joint Session with Society of Economic Geologists.

"Symposium on Ground Water Geology"—Organized by George W. White.

George W. White and V. T. Stringfield, Associate Chairmen.

"Geology of Ground Water in St. Louis City and County"	John G. Grohskopf Missouri Geological Survey

"Importance of Pleistocene Studies for Ground-Water Investigations in Kansas"	John C. Frye Geological Survey of Kansas
"Dry Weather Stream Flow as an Indicator of Geology and Ground Water"	R. J. Bernhagen Ohio Division of Water
"Electrical Well-Logging Equipment of the Iowa Geological Survey and Its Operation"	H. Garland Hershey and Wm. E. Hale Iowa Geological Survey and U. S. Geological Survey
"An Integrated Geophysical and Geological Investigation of Aquifers in Glacial Drift Near Champaign-Urbana, Illinois"	John W. Foster and Merlyn B. Buhle Illinois Geological Survey
"Ground Water in Tel Aviv, Israel"	Nicholas A. Rose Consulting Geologist Houston, Texas

GEOPHYSICS SUBDIVISION

Tuesday, February 20.

GEOPHYSICS SUBDIVISION.

9:00 A.M. Gold Room Jefferson Hotel

Joint Session with Mineral Economics Division.

Philip J. Shenon and Associate Chairman.

EXPLORATION ECONOMICS.

"Economics of Geophysics"	Sherwin F. Kelly President, S. F. Kelly Geophysical Services
"Cost of Geophysical Exploration"	Carl A. Bays Carl A. Bays and Associates
"A Graphic Statistical History of the Tri-State District"	John S. Brown St. Joseph Lead Co.
"Cost of Geophysical Prospecting for Minerals"	Oscar Weiss Weiss Geophysical Corp.

GEOLOGY SUBDIVISION.

Tuesday, February 20.

9:00 A.M. Ivory Room Jefferson Hotel

Joint Session with Society of Economic Geologists.

Symposium Organized by Roger H. McConnel on "Surface and Near-Surface Manifestations of Ore Bodies."

Ira B. Joralemon and Donald M. Davidson, Associate Chairmen.

"Surface Expressions of Veins in the Pachuca Silver District, Mexico"	C. L. Thornburg U. S. Smelting, Refining and Mining Co.

"Ore Shoots of the Bolivian Tin Deposits"	F. S. Turneaure Univ. of Michigan
"The Abnormal Copper, Lead, and Zinc Contents of Soil Near Metalliferous Veins"	Lyman Huff U. S. Geological Survey
"Guides to Ore in the Pachuca Silver District, Mexico"	Edward Wisser Univ. of California
"The Fairview Mine, Similkameen District, B. C."	C. O. Swanson Consolidated Mining and Smelting Co.

GEOLOGY SUBDIVISION

Tuesday, February 20.

2:30 P.M. De Soto Hotel

Joint Session with Society of Economic Geologists.

Symposium Organized by Roger H. McConnel on "Surface and Near-Surface Manifestations of Ore Bodies."

John W. Vanderwilt and John S. Brown, Associate Chairmen.

"Practical Significance of Alteration Haloes"	D. M. Davidson E. J. Longyear Co.
"Geologic Factors Leading to Negative Results in Exploration at White Pine, Tennessee"	Arnold Brokaw U. S. Geological Survey
"Shallow Expressions of Silver Belt Ore Shoots, Coeur d'Alene District, Idaho"	R. E. Sorenson Hecla Mining Co.
"Clay Alteration Associated with Uranium Mineralization"	Paul F. Kerr Columbia Univ.
"Outcrops in Limestones as Ore Guides"	Chas. H. Behre, Jr. Columbia Univ.

GEOLOGY SUBDIVISION.

Wednesday, February 21.

9:00 A.M. Gold Room (J) Jefferson Hotel

Joint session with Industrial Minerals Division and Society of Economic Geologists.

Symposium organized by A. F. Frederickson on "Clay and Laterite Relationships."

R. E. Grim and R. H. Sales, Associate Chairmen.

"Recent Advances in Clay Mineral Technology"	R. E. Grim University of Illinois
"Origin of the Arkansas Bauxite Deposits" I. Field Relations of the Deposits	M. Gordon, Jr. U. S. Geological Survey J. I. Tracey, Jr. U. S. Geological Survey

"Origin of the Arkansas Bauxite Deposits" II. Processes that Formed the Deposits	M. Gordon, Jr. U. S. Geological Survey J. I. Tracey, Jr. U. S. Geological Survey
"Observations on the Relations of Hydrous Aluminum Oxide Minerals to Clay"	V. T. Allen St. Louis University
"Occurrence and Exploration of Kaolin Deposits in Central Georgia"	T. L. Kesler Thompson, Weinman and Company
"On the Iron Oxides and Hydroxides in Laterites"	Robt. Mackenzie Macauley Institute, Scotland (Read by Robt. Roth University of Illinois)

Wednesday Afternoon SEMINAR Session.

A general seminar, presided over by Dr. Ralph E. Grim will be held. All of the authors who have presented papers will be present. All interested persons are also invited to attend. If someone wishes to contribute additional information and will require the use of the lanterns for the projection of slides, please inform the chairman in advance of the meeting so that suitable arrangements can be made.

GEOPHYSICS SUBDIVISION.

Wednesday, February 21.

9:00 A.M. Room No. 9 Jefferson Hotel

Hans Lundberg and James B. Macelwane, Associate Chairmen

Business Meeting

"Annual Review of Geophysics"	Sherwin F. Kelly S. F. Kelly Geophysical Services, Inc.
"Methods of Geothermometry being Developed at the University of Toronto, and Some Applications"	F. G. Smith, W. H. Little, and A. D. Mutch Univ. of Toronto
"Airborne Magnetometric Exploration in the Petroleum Industry"	Homer Jansen Aero Service Corporation
"Contribution of Geophysical Surveys to the Discovery of Stilfontein Gold Mine in South Africa"	Oscar Weiss Weiss Geophysical Corp.

2:00 P.M. Room No. 9 Jefferson Hotel

Sherwin F. Kelly and George B. Woollard, Associate Chairmen.

"The Application of Geophysical Methods of Underground Exploration in Civil Engineering"	George F. Sowers Georgia Institute of Technol- and Law-Barrow Agee Laboratories

"Case Histories of Resistivity Applied to Near-Surface Geology"	William W. Schwendiger and Walter J. Gabriel Mine and Quarry Services, Inc.
"Practical Results from Resistivity Methods as Applied to Ground-Water Problems in Arizona"	Samuel Turner U. S. Geological Survey
"Electrical Resistivity Measurements at the Meramec Plant Site, St. Louis County, Mo."	Le Roy Scharon Washington Univ.

GEOLOGY SUBDIVISION.

Wednesday, February 21.

2:00 P.M. De Soto Hotel

Joint Session with Society of Economic Geologists.

Carl Tolman and Roger H. McConnel, Associate Chairmen.

"The Interrelation of Mining Geology and Mineral Dressing"	F. W. Farwell and Donald W. Davis American Cyanamid Co.
"Mine Drainage Studies in the Iron Ranges of Northern Michigan"	Wilbur T. Stuart U. S. Geological Survey
"Origin of the Mississippi Valley Type Lead-Zinc Deposits—A New Hypothesis Extended"	A. F. Frederickson Washington Univ.
"Geology of the Hayden Creek Lead Mine, Southeastern Missouri"	Ernest L. Ohle St. Joseph Lead Co.
"Effect of Post-Ore Dike Intrusion on Butte Ore Minerals"	Reno H. Sales and Charles Meyer Anaconda Copper Mining Co.

Wednesday, P.M., February 21, 1951.

(Joint Session with Coal Division, AIME)

Clayton G. Ball, Chairman.

MISCELLANEOUS PAPERS ON COAL GEOLOGY.

1. Coal Resources Studies in the United States	By Paul Averitt
2. An oxidation Method for Investigating the Petrographic Composition of Some Coals	By R. Q. Shotts
3. Differential Thermal Curves of Selected Arkansas Coals	By C. M. Gamel, Jr. and W. J. Smothers
4. Cyclic Sediments and Engineering Geology	By S. S. Philbrick
5. Some Oxidation Effects on Coal Mine Roofs	By Charles T. Holland

Wednesday, A.M., February 21, 1951.

(Joint Session with Coal Division, AIME.)

Gilbert H. Cady and Paul H. Price, Associate Chairmen.

RECENT STUDIES ON COAL GEOLOGY
AND
SYMPOSIUM ON ACADEMIC AND LABORATORY ACTIVITIES ON COAL GEOLOGY.

1. A Review of Recent Published Studies on Coal Geology Exclusive of Resources	By A. T. Cross
2. Symposium on Current Academic and Laboratory Activities Relative to Coal Geology	
a. Arkansas	By J. Norman Payne
b. Illinois	Arthur Bevan
c. Indiana	Charles Wier
d. Iowa	Garland Hershey or L. M. Cline
e. Kansas	Walter Shoewe
f. Kentucky	C. S. Crouse
g. Missouri	Walter V. Searight
h. Oklahoma	Robert Dott
i. U. S. Geological Survey	James Schopf
j. U. S. Bureau of Mines	Bryan Parks
3. Meeting of the Coal Geology Committee of SEG	

Field Trips—Thursday, February 22, Southeastern Missouri Lead Belt. Friday, February 23, Tri-State Zinc District, leave 11:20 P.M. Thursday, February 22, return to St. Louis 7:25 A.M. Saturday, February 24.

INDUSTRIAL MINERALS DIVISION.

CANADIAN INDUSTRIAL MINERALS SESSIONS.

M. F. Goudge, Chief, Canada Department of Mines and Technical Surveys, *Canada's Wealth in Industrial Minerals.*

C. K. House, Newfoundland Department of Natural Resources, *Geology and Mining and Milling Practices at St. Lawrence Fluorspar Deposits, St. Lawrence, Newfoundland.*

P. E. Bourret, Quebec Department of Mines, *Industrial Minerals of Quebec.*

K. V. Lindell, Canadian Johns Manville Co., *Asbestos Mining at the Jeffrey Mine.*

A. J. Williams, Saskatchewan Department of Natural Resources, *Saskatchewan's Industrial Minerals.*

G. F. Miller, Saskatchewan Minerals Co., *Saskatchewan Minerals, Sodium Sulphate.*

Hartley Sargent, British Columbia Department of Mines, *Industrial Minerals in British Columbia and their Relations to Power, Fuels, and Markets.*

J. W. McCammon, British Columbia Department of Mines, *Windemere Gypsum Deposits, Rocky Mountains, British Columbia.*

GENERAL INDUSTRIAL MINERALS SESSIONS.

William C. Aitkenhead, State College of Washington, *Synthetic Mica. Research at the Colorado School of Mines.*

J. G. Miller, Westvaco Chemical Co. (repeat from Northwest Minerals Conference), *Elemental Phosphorus and the Commercial Importance of Molecularly Dehydrated Phosphates.*

Gordon F. Simons, Beryllium Corp.,—*Beryl*—a general paper.

B. R. Burnett and H. A. Meyerhoff, *Volcan Overo Sulphur Mine, Argentina.*

E. Gillerman, U. S. Geological Survey, *Factors Influencing the Localization of Fluospar in Southwestern Grant Co., New Mexico.*

J. E. Lamar, Illinois Geological Survey, *Occurrence and Properties of Southern Illinois Silica.*

Robert M. Grogan, Illinois Geological Survey, *Fluorspar Deposits of Mexico.*

Gerald M. Friedman, University of Cincinnati, *Origin of Emery Ore Deposits.*

J. E. Ryan, *Searles Lake Operation at Trona, Calif.*

Claire B. Laird, Eagle Iron Works, *Shale Planer.*

Michael J. Messel, Vermont Asbestos Mines, *The Ruberoids New Lowell Asbestos Mine and Mill.*

DIMENSION STONE SESSION.

R. H. Hoppin and L. A. Norman, Jr., *Some Economic Aspects of the Southern California "Black Granites."*

W. F. Mullin, Division of Mining, Pennsylvania State College, *Operational Studies in the Pennsylvania Slate Industries.*

W. P. Mould, Rock of Ages Co., *A Suggested Method of Quarrying a Boulder-Type Granite Formation.*

E. H. Lund, University of Minnesota, *Morton Granite Gneiss of the Minnesota Valley.*

G. A. Thiel and G. M. Schwartz,* University of Minnesota, *Dimension Stone in Minnesota.*

John B. Patton, Indiana Geological Survey, *Building Stones of Indiana.*

LIGHT-WEIGHT AGGREGATE SESSION.

K. E. Hamblen, Consulting Eng., Portland, Oregon, *Perlite in Oregon, Washington and Idaho.*

Clarence R. King, Consultant, *A Summary Statement of Perlite Trends.*

*Author.

Norman Plummer, Kansas Geological Survey, *Light-weight Aggregate from Kansas Clays.*

Staff, Battelle Memorial Institute, *Economics of Light-weight Aggregate in the United States.*

CLAY TECHNOLOGY SESSION.

Independent.

G. W. Phelps, G. W. Lee and G. G. Brun, United Clay Mines Corporation, *Ball Clays: Control Testing Applied to Exploration and Mining.*

Poole Maynard, Industrial Geologist, Atlantic Coast Lines, *Origin, Processing and Application in the Trades of "Florida Phosphate Slimes."*

J. B. Chatelain and M. F. DuFour, Micronizer Co., *Grinding to Sub-Sieve Ranges with Jet Pulverizers.*

W. J. Smothers and Theodore Dziemianowicz, University of Arkansas, *Ceramic Investigation of an Arkansas Clay Deposit.*

MINERAL ECONOMICS SESSIONS.

Piere deVitry and W. P. Mould, *The Henry Fayol Method of Administrative Organization.*

Olaf P. Jenkins, Chief, California Division of Mines, *California's Mineral Position in a Changing Industrial World.*

John Ames, Geologist-Engineer, B. & O. RR., *Economics Trends of Fluxstone—Middle Atlantic Area.*

J. D. Turner, U. S. Geol. Survey, *Mineral Leasing on Government Acquired Lands.*

Abstracts of papers to be presented at the joint Annual Meeting of the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers at St. Louis, Missouri, February 19–21, 1951.

THE COMPOSITION OF ARGILLACEOUS ROCKS IN RELATION TO THEIR CONDITIONS OF GENESIS.

GEORGES MILLOT.

Many samples of argillaceous rocks have been collected from sedimentary formations with definite and characteristic conditions of genesis. The clay mineral composition of the samples has been determined, and it is shown that the association of clay minerals changes with the environment of decomposition. Kaolinite distinguishes the continental lakes with fresh, aggressive, and acid waters. The minerals of the micaceous types distinguish the salt lagoons and the environments rich in cations. The marine environment shows mixtures in which the micaceous minerals generally prevail.

Such a statistical analysis permits reciprocal analysis of conditions of deposition of ancient sediments from their clay mineral composition, in spite of exceptions, some of which are discussed. It is necessary to proceed cautiously, and the rules to be followed in applying such analysis in a new area are indicated. Among these rules, the chief ones are stated for sedimentary kaolins, attapulgites and common clay rocks.

EFFECT OF POST-ORE DIKE INTRUSION ON BUTTE ORE MINERALS.

RENO H. SALES AND CHARLES MEYER.

Post-ore rhyolite dikes cut the ore-bearing veins in the Butte District. Pyrite-bearing chalcocite ore, typical of the Central Zone, is converted to massive bornite and chalcopyrite adjacent to the dikes. The reaction is interpreted as a duplication in nature, of furnace experiments in which similar products were obtained by heating chalcocite and pyrite together in the absence of excess sulphur. Textures suggestive of exsolution are present in the bornite-chalcopyrite aggregates produced at the contact with the dikes and also in incompletely reacted chalcocite-bornite masses farther from the dike where the metamorphism is less intense. The full width of the reaction zone ranges from a few inches to twenty feet.

Other vein mineral changes have also been observed at dike contacts at Butte. Pyrite, in the absence of copper sulphides, is locally desulphidized to hematite; enargite may be partially converted to tennantite; and, along a north-south trending dike in the southwestern part of the district, rhodochrosite is studded with fine granules of alabandite.

The dike rocks are extensively hydrothermally altered, principally to various mixtures of clay minerals including a member of the illite group. A few exposures have been observed where minute sulphide stringers unmistakably penetrate the dike. It is believed that the dikes were emplaced after all of the ore had been deposited, but before the dying phases of main-stage hydrothermal activity had ceased completely.

AN INTEGRATED GEOPHYSICAL AND GEOLOGICAL INVESTIGATION OF AQUIFERS IN GLACIAL DRIFT NEAR CHAMPAIGN–URBANA, ILLINOIS.*

JOHN W. FOSTER AND MERLYN B. BUHLE.

Electrical earth resistivity surveys, extensive test drilling, and the electric logging of borings near Champaign-Urbana have provided abundant information

* Presented with permission of the Chief, Illinois State Geological Survey, Urbana, Illinois.

for geological study of glacial drift aquifers. This investigation makes possible and encourages an efficient development of the available groundwater resources for public, industrial, and domestic use throughout a three-hundred-square-mile area.

The basic geology of the bedrock surface and of the overlying Kansan, Illinoian, and Wisconsin drift mantles is described, together with the techniques of electrical prospecting on the ground surface, electric logging of rotary borings in glacial drift and the collection and study of drift samples. The integration of composite electrical data with geologic studies provides valuable information on the distribution, thickness, permeability, confinement and origin of scattered water-bearing formations above the bedrock surface. Electrical and geologic cross sections show the regional relations of the aquifers with buried bedrock surface topography which includes the deep Mahomet (Lower Teays) valley.

The investigation yields information on numerous water-bearing deposits which are untapped and suitable for extensive industrial exploitation in addition to other aquifers available for municipal and domestic groundwater development. The Champaign-Urbana study—a type investigation—reveals the presence of buried sands and gravels whose potential groundwater resources within economic reach of the community greatly exceed total demand for the foreseeable future.

STRUCTURAL GEOLOGY AS THE SETTING FOR MINING OPERATIONS.

EDWARD WISSER.

The geologic structure of a mine forms the setting in which all mining operations, from the initial exploration to the final stoping, take place. From the standpoint of the operation as a whole it is the size, shape, attitude and distribution of the ore bodies that determines the nature of the mine workings, the direction and sequence in which they are driven and the manner in which they are spaced.

Mining design involves planning a campaign to explore, develop and mine an ore deposit. It demands ability of the designer to predict behavior of ore structures beyond the places where they are exposed. Especially with manto-chimney deposits, remarkable for their continuity, slender ore bodies may be followed a mile or more without understanding the whys and wherefores of their occurrence; but the behavior of such ore bodies is unpredictable and mining design has a minimum application in their exploitation.

At the opposite extreme is a regular persistent vein, the position of which may be predicted with confidence below or to one side of its exposures. Here mining design finds its maximum application.

Examples are given of the effect of structure on the planning of exploration and development campaigns. The paper concludes with some generalizations on the geometry of exploration. Exploration targets may be two-dimensional, such as a tabular vein; undimensional, such as the intersection of a favorable limestone bed with a transverse "feeder" fracture; or the target may be a point, without dimensions, such as the intersection of a limestone bed with two sets of "feeder" fractures.

DESIGN OF UNDERGROUND MINES.

R. L. LOOFBOUROW.*

This paper proposes a means of reducing the cost of mine development and mineral production through the earliest possible utilization of all information enabling an engineer to design underground development for most efficient completion and for appropriateness to the needs of production. This is not meant to be of academic interest only. The procedure to be suggested has been applied to several undertakings and modifications of it have been used to design mines now producing efficiently.

* Manager, Mine Contracting Division, E. J. Longyear Company, Member, AIME.

Particular stress is laid on core drilling and observations made as this drilling progresses.

The procedure is considered applicable to any deposit that may be satisfactorily explored by core drilling. It is felt that the proportion of these deposits is continually increasing because of improvements in drilling equipment and technique.

Information needed by the engineer to design a mine may be classified as follows:

1. External Factors controlling accessibility, type of construction, location of access workings. These may be determined by observation and mapping.
2. General Factors such as financial status of the operating company, economic status of the area, and market aspects control many broad phases of planning. They must be sought out.
3. Dominant Features of Orebody and Enclosing Rocks such as value, geometry, geological environment, and nature of walls control the major outline of underground work. They may be determined from core drilling.
4. Physical and Chemical Character of Ore, Walls and Cover shape the conditions under which underground work will be done, and indicate the detailed means for doing it. They may also be determined by drilling.
5. Treatment indicates net recoverable value, a cost which must be approximated to evaluate total costs; hence, limits means of attack; it may restrict type of product. It may be determined by study of core and assay rejects saved for the purpose.

Means of determining some of this information from core drilling are stated.

Analysis of the foregoing information will lead first to the selection of the most appropriate stoping method, then to, a) design of gathering, stope ventilation and access facilities, with cost estimates, b) design of mine transportation and mine ventilation, c) summary of design and logical integration of all portions, d) full estimate of costs.

With development laid out in a manner appropriate to the needs of mining, it will be possible to appraise a number of alternative ways by which to enter the mine. Choice between them may depend on timing, on equipment and manpower immediately available, on cost, or on the need to check any of the conditions observed or deduced from drilling.

GEOLOGY OF GROUND WATER IN ST. LOUIS CITY AND COUNTY.

JOHN G. GROHSKOPF.

Potable water in sufficient amount for domestic use is obtained from wells in limestones of Mississippian and Ordovician age in some parts of the area, but these formations produce sulpho-saline water which is non-potable in other parts of the area. All these formations occur above the St. Peter sandstone which underlies the entire area. The St. Peter produces larger yields of water than do the limestones, but mineralized water occurs in it in St. Louis City proper and in extreme northeastern St. Louis County, while in some other parts of the County, fresh water is found in the St. Peter. There is a direct geologic relationship to the occurrence of either type of water. Mineralized water may be expected away from the outcrop, downdip in the eastern and northeastern part of the area from the St. Peter sandstone. The same is true in a lesser degree of the limestones since the type of water in them seems also to be governed, at least in part, by the presence or absence of certain shales which act as an impervious blanket and prevent fresh water from migrating into these limestones. Large supplies of water for commercial and industrial uses can be obtained from wells in the unconsolidated alluvium present at places along the major streams.

IMPORTANCE OF PLEISTOCENE STUDIES FOR GROUND-WATER INVESTIGATIONS IN KANSAS.

JOHN C. FRYE.

The occurrence of ground water in Kansas is closely linked to the character and distribution of Pleistocene sediments as approximately 60 percent of the State's potable ground waters occur in deposits of that age. Widespread intensive investigations of ground-water resources and studies of Pleistocene stratigraphy have had a parallel steady growth during the past 12 years. The Federal and State Geological Surveys, assisted by the State Boards of Agriculture and Health, have maintained a cooperative ground-water program during this period. Pleistocene studies carried out both by the cooperative ground-water division and other divisions of the State Survey have proved indispensable to the valuation of ground-water resources. Interdependence of these studies is particularly apparent in regions crossed by filled and abandoned Pleistocene valleys; in the glaciated region where permeable sands are unpredictable by surface methods; along valleys flanked by a succession of alluvial terraces; and in areas where recharge is importantly influenced by surficial mantles of loess or dune sands, by buried soil profiles, or by the character and trend of obscured gravel deposits. Furthermore, a desirable degree of uniformity in ground-water reports has been possible in recent years by development of a single state-wide classification of Pleistocene deposits based on correlation studies using fossil molluscan faunas, buried soil profiles, physiographic expression, volcanic ash petrography, and lithologic characters. In turn ground-water investigations, particularly data obtained by the Survey-owned test drill, have been vital to an adequate understanding of Kansas Pleistocene geology.

DRY WEATHER STREAM FLOW AS AN INDICATOR OF GEOLOGY AND GROUND WATER.

RALPH J. BERNHAGEN.

A selected group of flow duration curves for Ohio streams has been plotted on logarithmic probability scales in terms of cubic feet per second per square mile. The wide differences in shape of curves for these streams, particularly in the lower ends of the curves, reflect the influence of the geology of a basin on stream flow. An index of dry-weather flow is arbitrarily established for each basin as the flow in cubic feet per second per square mile that is exceeded 90 percent of the time. This index approximates the modal or most common rate of flow and is used to designate that part of stream flow which is discharged from subterranean storage. The duration curve and index of dry-weather flow are supplementary tools for the geologist in the study of geology and ground water.

ELECTRICAL WELL-LOGGING EQUIPMENT OF THE IOWA GEOLOGICAL SURVEY AND ITS OPERATION.

H. GARLAND HERSHEY AND WILLIAM E. HALE.

Many water wells in Iowa penetrate thick sections of limestone, dolomite, and sandstone. Commonly, these rocks are left entirely uncased in a well so that several aquifers may be open. Electrical well-logging equipment was acquired by the Iowa Geological Survey in 1949 to obtain supplemental information on the occurrence of water in these individual aquifers, primarily for the regional ground-water investigations carried on in cooperation with the U. S. Geological Survey. To date logging has been confined to finished wells that have been temporarily out of use or abandoned.

The well-logging equipment consists of a caliper, salinity meter, flow meter, logging electrode, and thermometer operated individually on 2,800 feet of four-

conductor cable. The instruments use direct current obtained by rectifying alternating current. A continuous record from the instruments is obtained by means of a recording milliammeter, which can be geared to a depth indicator or operated on a time basis.

A caliper log provides data on the position and size of casing and on caved or creviced sections, and it is essential for accurate flow-rate determinations. A U. S. deep-well current meter is used to obtain velocity measurements as small as 3 feet a minute. Smaller velocities are measured by means of spot salting and use of the salinity meter. Temperature and conductivity measurements are used to indicate points where water enters or leaves a well. Self-potential and resistivity curves provide data on the geologic section.

GROUND WATER IN TEL AVIV, ISRAEL.

NICHOLAS A. ROSE.

Tel Aviv lies at the western edge of the Central Coastal Plain of Israel on the shore of the Mediterranean Sea. Geologically, the coastal plain is a wedge of Plio-Pleistocene deposits resting on Saqiya and Eocene strata which overlay Turonian and Cenomanian formations. The Plio-Pleistocene sediments, from which Tel Aviv obtains its ground water, range in thickness from a feather edge to about 150 meters and are made up chiefly of sand and sandstone. In southern Tel Aviv a thick clay stratum occurs in the lower part of the formation.

The Tel Aviv water supply is obtained from 37 wells ranging in depth from 17 to 150 meters. From 1933 to 1949 the water level in the general area declined an average of 6 meters. The center of the cone of depression which is about 1,500 meters from the shore is approximately 5 meters below sea level.

Mineralization of water from a small group of wells in the northwestern section has increased sharply due to the encroachment of salt water from the sea. Water from wells in the southern and eastern sections thus far has not shown material increases in mineralization.

In order to halt salt-water encroachment a freshwater barrier must be created along the coastal area and withdrawals must be distributed over a much larger area. It is proposed that existing wells nearest the coast be abandoned and three new well fields of 9 wells each be developed—one north, one east, and one south of the city.

THE SURFACE EXPRESSION OF VEINS IN THE PACHUCA SILVER DISTRICT, MEXICO.

C. L. THORNBURG.

Pachuca is a silver vein district in a mountain range which consists of Tertiary volcanic rock, predominantly andesite. One of the peculiar features of this great district is that many of its veins lie so far below the surface that they show no outcrops. The upper limits of these particular veins are in numerous cases over a thousand feet below the surface, this being true not only of the tops of ore but also of the upper limits of the veins themselves. At their upper extremities the veins narrow down to minor fractures, which though discernible have practically no quartz or other gangue minerals.

Those veins which are exposed at the surface were extensively exploited in past centuries, although early operations were handicapped against deeper work by inadequate means of handling water. The veins which do not reach the surface are mainly the ones which have been developed in modern times and which have yielded the bulk of the production in recent decades.

Pachuca veins are invariably associated with moderate hydrothermal alteration which pervades wall rock and extends far above the practical limit of metal and quartz deposition. The alteration consists mainly of the development of chlorite,

sericite, and fine disseminated pyrite. Chloritization, the most common and widespread effect, tends to be moderate though general. Sericitization and pyritization are much less extensive than chloritization. Weathering of andesite which has been extensively pyritized produces a characteristic type of iron-stained surface which is common in and adjacent to productive areas.

The surface expression of one or more veins may be nothing more than an area of discolored andesite, resulting from hydrothermal alteration and the later, superimposed effects of oxidation. Since this alteration is much more extensive than metallization, its relationship to veins is not sufficiently definite to be a reliable guide in exploration. On the other hand, a definite relationship does exist in certain cases which show the intensity of surface alteration to be directly proportional to the proximity of the upper limit of metallization.

ORE-SHOOTS OF THE BOLIVIAN TIN DEPOSITS.

F. S. TURNEAURE.

The occurrence of ore in the Bolivian region is well illustrated by the four major tin-producing districts, Potosi, Llallagua, Huanuni and Colquiri.The numerous veins of Potosi and Llallagua are closely associated with small bodies of quartz porphyry, whereas the veins of Huanuni and the composite lode of Colquiri are enclosed in shale or sandstone. All four deposits represent shallow, high-temperature mineralization of the xenothermal type.

Many individual veins are characterized by ore-shoots of exceptional grade but of limited vertical extent. The elevation of the high-grade ore varies widely in the individual veins and vein groups; its position shows little relation to details of vein structure or to changes in wall rock.

Veins which outcrop in the central, tin-bearing zone of the major districts have a good chance of being productive in depth. In future exploration, more attention will have to be given to the low-grade veins of the marginal zones and to the mineralized but less productive districts. In the appraisal of outcrops and of veins exposed in shallow workings, mineral association may prove helpful. Minerals which may be considered favorable are wolframite, bismuthinite, pyrrhotite, and possibly arsenopyrite; abundant pyrite and sphalerite are unfavorable. Quartz is more common than siderite in the high-grade veins. The true significance of fluorite as a vein mineral and of tourmaline as an alteration product is uncertain. Extremely narrow seams containing visible cassiterite or wide veins with small patches of cassiterite offer better possibilities than wide veins with a consistent but low tin assay.

The principles of rock alteration are difficult to apply in the search for ore in the Bolivian region because of the extreme variation both in the intensity of alteration and in the geological setting of the tin deposits.

*THE ABNORMAL COPPER, LEAD, AND ZINC CONTENT OF SOIL NEAR METALLIFEROUS VEINS.**

LYMAN C. HUFF.

Samples of both normal soil and soil near metalliferous veins were tested to investigate the behavior of copper, lead, and zinc during the formation of residual soil. The copper, lead, and zinc content of normal soils is of the same general magnitude as the 50 to 100 parts per million of each metal found in unmineralized rocks. Only slightly higher amounts of these metals are found in soils from hillsides just above most of the fourteen veins studied. The soil at the vein or immediately downhill from the vein commonly contains much higher concentrations of these metals and may contain as much as 10,000 parts per million (1 percent). The ratios of the extreme high and low metal values determined near each vein are as much as 106 to 1 for copper, 170 to 1 for lead, and 11 to 1 for zinc.

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The geochemical anomalies near most veins can be located by sampling surface soil at 50- or 100-foot intervals and analyzing the samples by quick or "field-type" methods. Chemical analyses of soils revealed the location of some veins even though they were completely hidden by residual soil. Two examples are described where chemical methods were used to locate concealed extensions of known veins.

GUIDES TO ORE IN THE PACHUCA SILVER DISTRICT, MEXICO.

EDWARD WISSER.

An ore guide is usually a combination of structure, mineral assemblage and host rock which suggests an outer portion, whether top, side or bottom, of a setting enclosing an ore body. The guide points downward, laterally, or upward toward the hoped-for ore body.

Such a guide is empirical if the reason for its acceptance as a guide lies in the fact that ore has been found elsewhere in settings that look similar to the one in question, and if the underlying reasons for the preference shown by known ore for such settings are not understood. Use of empirical ore guides far from known ore is dangerous, for an ore setting in one district may have had a history very different from that of a similar-looking setting in another district.

Ore settings seen today are inert but the history of ore formation is a record of dynamic events: the solutions moved and the walls of the fracture within which the ore body deposited commonly moved also at the time the ore body formed.

Deciphering this dynamic record may be termed *tectonic analysis*. The Pachuca silver district is used as an example of the application of this tool to exploration; its possible utilization in the evaluation of virgin districts is emphasized.

THE FAIRVIEW MINE, SIMILKAMEEN DISTRICT, B. C.

C. O. SWANSON.

The Fairview mine is of interest in a discussion of the surface manifestations of ore shoots because the exploration of the property owes much of its success to the testing of a buried structure that is indicated by the outcrops. This structure consists of an abrupt change in the strike and dip of the beds that contain the quartz veins, forming something resembling a hinge. The early adits followed narrow bedded veins that lie in the gently dipping limb above the hinge. It was then observed that better ore bodies made their appearance at a point on the 5th level where the beds bend to the west and steepen in dip. Subsequent work found large quartz bodies on the steep limb below the hinge.

Shearing that is clearly earlier than the mineralization is strongly developed near the hinge and for some distance down the steeply dipping limb, where it is only slightly oblique to the bedding. Thus the relations are those that might be met in crossing a large pre-mineral fault. However, there is no evidence of any great displacement along the zone, and it is believed that the broad control is best described as a sharp flexure with associated shearing.

In detail, the quartz tends to follow either the bedding or the shearing. The ore is mined as a silica flux containing low values in gold and silver as well as very minor amounts of galena and sphalerite.

SHALLOW EXPRESSIONS OF SILVER BELT ORE SHOOTS, COEUR D'ALENE DISTRICT, IDAHO.

ROBERT E. SORENSON.

The productive Silver Belt of the Coeur d'Alene is responding to deeper development of geologically favorable areas. Precambrian argillite and quartzite are folded and faulted along easterly-westerly trends. "Bleached zones" follow

prominent structural features and the bleaching solutions destroy original rock structures, textures and colors. Abundant sericite, disseminated carbonate and sporadically distributed pyrite are common. In some areas the bleaching phase is preceded by abundant chloritization.

Bleaching was succeeded by structural adjustments and quartz-carbonate-pyrite veins were developed along minor tensional fractures or shear zones of little displacement. Further adjustments were followed by emplacement of the sulphides and associated quartz and carbonate.

Tops of productive shoots may lie several thousand feet below the surface and may require more than a million dollars to reach them. Only meager criteria indicating deep-seated ore shoots may appear at shallow horizons. Zones of intense bleaching in association with a strong structural environment appear to be the initial targets. Within such zones areas of prolific veining of quartz and carbonate may be observed at shallow horizons above productive ore shoots. Such carbonate may be calcite, ankerite or siderite, although at increasing depths siderite becomes predominant. Careful investigation of such veins is likely to reveal one or more structures which contain minor quantities of tetrahedrite, chalcopyrite, sphalerite and galena. Dip projection of the locus of the sparsely mineralized veins is likely to mark the objective of deeper development projects.

The paper describes shallow characteristics and points out some probable relationships to ore bodies. Other characteristics and possible ore controls in the area are discussed.

OBSERVATIONS ON RELATIONS OF HYDROUS ALUMINUM OXIDE MINERALS TO CLAY.

VICTOR T. ALLEN.

Gibbsite, boehmite, and diaspore deposits of the United States have been studied petrographically by the writer and the results checked by X-ray, differential thermal, and chemical methods. Also the volume relations and the porosity of bauxite, secondary kaolin, boehmite, and diaspore clay have been determined. These observations indicate that desilication, the removal of silica from silicate minerals and clay to form hydrous aluminum oxide or other clay minerals, may take place with the preservation of the original structure of feldspars or of sedimentary kaolin. This is the most important process in the formation of clays and bauxite deposits. Resilication, the addition of silica to gibbsite to form a hydrous aluminum silicate or clay, can take place with the preservation of the original structure only where some alumina is liberated and migrates to another part of the deposit. At some deposits this process has operated, but in general it is not responsible for large bodies of residual and sedimentary clay. Migration of hydrous aluminum oxides and clay minerals results in an addition of volume to the parent rock that distorts or destroys its original structure. The addition of secondary kaolin by migration at some bauxite deposits has obscured the true effects of early desilication and has prevented some observers from recognizing the operation of this early process in its proper perspective.

INVESTIGATIONS ON THE ORIGIN AND DETECTION OF COLD-PRECIPITATED HYDRATED FERRIC OXIDE IN CLAYS.

R. C. MACKENZIE.

The presence of "cold-precipitated" hydrated ferric oxide in a considerable number of clays has been demonstrated by differential thermal analysis.* In soils its occurrence is so widespread that it has not yet been possible to correlate it with any particular soil type. Consequently, in an attempt to gain some insight into the conditions under which the material forms naturally, pure laboratory-prepared mate-

* R. C. Mackenzie, Nature, 1949, vol. 164, 244.

rial has been studied. Small changes in the mode of preparation have been found to give relatively large changes in the thermograms obtained, and some curves exemplifying these changes are shown.

This material although, apparently, so common (at least in small amounts) gives an electron diffraction pattern dissimilar to those of all iron oxides so far examined. It is of two small particle size to give a sharp X-ray pattern, but on recrystallizing, after calcining ,the X-ray pattern is readily obtainable, and is again entirely new. After calcining a clay, it is therefore possible to detect its presence by X-rays.

THE INTER-RELATION OF MINING GEOLOGY AND MINERAL DRESSING.

FRED W. FARWELL AND D. W. DAVIS.

In practice and in the philosophy of many geologists mineral dressing and mining geology are sometimes widely separated. Some mining geologists seem to have little appreciation of their responsibility to mineral dressing or the bearing of mineral dressing on their field. Actually, mining geology and mineral dressing have three significant areas of contact, which become more important as lower-grade and more complex source materials are attacked:

1. Geology applied to mineral dressing:

Studies of the mineralogy and petrology of mineral deposits in anticipation of concentration, and mineralogical examinations of mill products in parallel with concentration serve to guide and evaluate mineral dressing practice.

2. Influence of mineral dressing upon mineral economics:

Other factors remaining constant, improvements in mineral dressing techniques and increasing scope of their applications are continually lowering the minimum grades of material that may be mined at a profit and in some cases are revising the physical specifications for ore. These revisions offer increased responsibilities to the mining geologist.

3. Ore discovery in relation to mineral dressing advance:

Conversely, the discovery of new ores and potential ores by geologists acts as stimuli to mineral dressing research, which may in turn develop new devices or adaptations.

It is the purpose of the balance of this paper to elaborate on Areas 1 and 2 by the use of illustrated examples from flotation and Heavy-Media practice. It is believed that such elaboration will point up most aspects of the interplay between mineral dressing and mining geology. If mining geologists and mineral dressing engineers are helped to better mutual understanding and coöperation, the greatest hopes for this paper will have been realized.

THE GEOLOGY OF THE HAYDEN CREEK LEAD MINE, SOUTHEASTERN MISSOURI.

ERNEST L. OHLE.

The Southeast Missouri District is one of the great lead-producing areas of the world. Typically, the ore is a bedded replacement of selected layers in the Bonneterre dolomite formation of upper Cambrian age. The Lamotte sandstone underlies the Bonneterre and, in most places, separates it from a Precambrian igneous complex of granites and flow rocks. Locally, quite steep dips in the sediments reflect irregularities in the buried Precambrian topography.

The mineralogy of the ore, in general, is simple and the precious metal content is low. Small amounts of zinc, copper, cobalt, nickel, silver, and cadmium are recovered. The beds are nearly horizontal and large tonnages are moved by mechanical equipment from mines which are within a few hundred feet of the surface.

The newly developed Hayden Creek Mine of the St. Joseph Lead Company is in an ore body that presents an interesting variation from the usual Southeast Missouri type. The metallization itself is quite normal but the host rock, instead of being dolomite, is a mass of granite boulders. The granite is Precambrian and the boulders are, in part, a basal conglomerate. Most of the ore, however, is in a lens of boulders that, early in Bonneterre time, rolled or slid down the side of a partially buried Precambrian hill and out on top of the Lamotte sandstone. There they were cemented together with sandy dolomite as the lowermost part of the Bonneterre formation. The ore replaces the cement and fills cracks in shattered boulders. Many of the boulders are completely bleached by weathering but some of them have fresh granite interiors.

METHODS OF GEOTHERMOMETRY BEING DEVELOPED AT THE UNIVERSITY OF TORONTO, AND SOME APPLICATIONS.

F. G. SMITH, W. H. LITTLE AND A. D. MUTCH.

DETERMINATION OF THE TEMPERATURE AND PRESSURE OF FORMATION OF MINERALS BY THE DECREPITOMETRIC METHOD.

F. GORDON SMITH.

Sorby's discussion of inclusions in minerals is reviewed and extended. The general theory of use of both fluid and solid inclusions, or two or more types of solid inclusions, to give a unique solution of both temperature and pressure of crystallization of any one mineral is described. A brief review is given of development of decrepitation analysis by which the temperature of filling of fluid inclusions by the liquid phase and the temperature of fit of solid inclusions can be determined.

LOW TEMPERATURE MINERALIZATION IN THE CANADIAN SHIELD, AND ITS RELATION TO GOLD DEPOSITION.

W. H. LITTLE.

The quartz veins found in the Archean part of the Canadian Shield are usually considered to be hypothermal in type. Fluid inclusions with degrees of filling characteristic of high temperature deposition have been found, but frequently later sets of inclusions characteristic of much lower temperature conditions have also been detected, both optically and by the decrepitation method. In all cases studied, gold-bearing quartz veins contain the low temperature inclusions, and variations in their degree of filling have an apparent relation to the distribution of the gold. The tentative conclusion is that the gold mineralization is later than, and superimposed on, the bulk of the quartz deposition.

VARIATIONS IN THE THERMO-ELECTRIC PROPERTIES OF PYRITE IN ASSOCIATION WITH GOLD ORE.

A. D. MUTCH.

Since the development of the pyrite geothermometer, several large scale tests of the instrument have been carried out. The results of two of these studies, in which determinations were made of pyrite in association with gold ore, are discussed. Wide variations in the thermo-electric potentials of the pyrite were found, with the pyrite from ore shoots and in association with free gold tending to have positive thermo-electric potentials and the pyrite not in ore tending to have negative thermo-electric potentials. Although there are some exceptions, the nature of the pattern obtained suggests an economic application of the technique.

CONTRIBUTION OF GEOPHYSICAL SURVEYS TO THE DISCOVERY OF STILFONTEIN GOLD MINE IN SOUTH AFRICA.

OSCAR WEISS.

The results of gravimeter, ground magnetometer, and aerial magnetometer surveys are presented in the area, and around the new Stilfontein gold mine, in the Klerksdrop District of the Transvaal in the Union of South Africa. The gravimeter and ground magnetic survey were completed in 1947–1948. The gravity anomalies suggested a block of Upper Witwatersrand quartzites faulted up between denser rocks of Dolomite and Ventersdorp Lava. Bore holes were drilled in 1948 and, after penetrating the Dolomite and Ventersdorp Lava, entered Upper Witwatersrand quartzites and intersected the Gold Estates Reef and Vaal Reef. Subsequent drilling delineated the sub-outcrop of the Vaal Reef of this horizon. The gold content of the Vaal Reef was highly payable and shaft sinking is now in progress.

THE APPLICATIONS OF GEOPHYSICAL METHODS OF UNDERGROUND EXPLORATION IN CIVIL ENGINEERING.

GEORGE F. SOWERS.

The geophysical methods of underground exploration, employed so extensively in mining and petroleum investigations, are now being used to a limited extent in civil engineering. The requirements of civil engineering investigations are different from those of mineral exploration; therefore, somewhat different techniques have been developed for this work. The geophysical methods have proved economical and time-saving in preliminary explorations to determine the depth of soil overlying rock, the location of ground-water, and the availability of sand and gravel deposits. On the other hand, they are of only limited use in determining the physical properties of soils and rocks and in determining the detail of underground conditions.

THE ORIGIN OF EMERY DEPOSITS.

GERALD M. FRIEDMAN.

The emery deposits of the United States are confined to the Appalachian belt. The ore occurs in norites, amphibolites, and probably peridotites. The persistent presence of granites close to emery deposits is conspicuous. Aplites, pegmatites or quartz tourmaline veins are observed to cut the basic rocks. A study of the literature of foreign emery deposits agrees with the pattern observed in the United States.

Emanations from the consolidation of the granite bodies are believed to have reacted with the basic rocks. A study of the critical phases of the latter as well as of the emery deposits shows that the destruction of the minerals of the norite in the Cortlandt Eruptive Complex was accompanied by a simultaneous formation of the emery minerals. Close to the outer border of the intrusion reactions with the wall-rock enclosing the complex are noted; here the destruction of the critical minerals of the emery and the separate stages in the formation of cordierite, sillimanite, and garnet can be observed. The deposits of Massachusetts, Virginia and North Carolina suggest a similar derivation but the cordierite-garnet zone was not observed.

In all these cases the influence of the granite is indicated by structural relations and by the typical suite of minerals containing volatile constituents.

CLASSIFICATION OF TEXTURES OF ORES.

G. M. SCHWARTZ.

The microscopic study of ores has been extensive during the past forty years, but a satisfactory classification and definition of textural terms has not been forthcoming. A preliminary list of textural terms taken from the literature and arranged in groups according to origin is given herewith. The terms will be defined and their general significance discussed.

List of Ore Textures and Structures.

Primary.

1. Banded texture.
2. Caries texture.
3. Cement texture—replacement of cement by ore minerals.
4. Cockade texture.
5. Colloform or gel texture, Leisegang rings.
6. Comb texture.
7. Crystallographic texture.
8. Dendritic, pseudodendritic, ice flower texture.
9. Diabasic texture.
10. Equigranular, granular, allotriomorphic, polyhedral or mosaic texture.
11. Fibrous, feathery, or plumose texture.
12. Foliate texture.
13. Granule texture—rounded grains, primary rounding in origin.
14. Graphic, myrmeketic, or pseudoeutectic texture; also subgraphic texture.
15. Herringbone texture.
16. Mottled texture.
17. Mutual boundary texture.
18. Oolitic, pisolitic, concretionary, concentric, scaly texture.
19. Porphyritic and porphyroblastic texture.
20. Rosette texture.
21. Spherulitic or radiating aggregate texture.
22. Wire texture.

Secondary.

1. Box work texture.
2. Brecciated, "exploding-bomb," or crushed texture.
3. Core or atoll texture.
4. Filiform texture.
5. Granulated, mylonitic, or microbrecciated texture.
6. Ice-cake texture.
7. Organic or cell texture.
8. Relict texture.
9. Rim texture.
10. Rumpled texture.
11. Septarian texture.
12. Serrate texture.
13. Shredded texture or shred-like texture.
14. Translation twinning texture.
15. Veined and reticulate texture.
16. Herringbone texture.

Ex-solution Textures.

1. Crystallographic or oriented intergrowth textures.
   (a) Lattice, lamellar or Widmannstatten texture.
   (b) Triangular texture.
   (c) Seriate texture.

2. Cell, cellular, net or mesh texture.
3. Emulsion texture.
4. Oleander-leaf texture.
5. Pseudoeutectic or graphic texture.
6. Entectoid texture.

Mineral Structures.

1. Cleavage.
2. Herringbone structure.
3. Lamellar twinning structure.
4. Polysynthetic twinning structure.
5. Zonal structure.
6. Skeleton structure.

THE FORMATION OF LATE MAGMATIC OXIDE ORES.

ALAN M. BATEMAN.

In basic magmas the oxides of iron and titanium and in part of chromium, along with volatiles, become enriched in the residual magma, and are the last, or among the last, minerals to crystallize. This heavy residual liquid trickles down through the interstices of early crystallized silicates to form a *late gravitative liquid accumulation* which rests upon a solid floor of early crystallized silicates. The down trickling heavy residual liquid makes room for itself by floating upward plagioclase crystals, bending and jostling some of them, to form overlying anorthosite. The residual liquid accumulation undergoes purification by eliminating the remaining silicate constituents; the degree of this purification determines the richness of the resulting ore deposit. If the residual liquid accumulation crystallizes under quiescent conditions a concordant or stratiform deposit results, e.g. Bushveld titanomagnetite layers. If pressure is exerted before final consolidation, the mobile residual liquid accumulation is squirted elsewhere, either along the structure of the host rock or transgressing structure, to form late magmatic injections somewhat similar to, but differing from filter pressing, e.g. Taberg and Kiruna, Sweden, Adirondacks, Allard Lake, Quebec, platinum pipes of South Africa. Residual liquid accumulation accounts for many purified magnetite and ilmenite deposits, and some chrome deposits, that lie concordantly within the parent rocks where evidence of squeezing is lacking, and for many late magmatic injected deposits.

OUTCROPS IN LIMESTONE AS ORE GUIDES.

CHAS. H. BEHRE, JR.

The criteria here discussed are particularly those characteristic of lead and zinc ores. Gossans should be most useful clues but despite pioneering by Locke, Blanchard and Boswell, too little is yet known about their mineralogy, color, and texture above rich, as opposed to lean ore bodies. Copper, if associated, is an aid in estimating intensity of mineralization. Lead, being stable, is especially useful. Chemical analyses of the gossan, indigenous plants or their ashes, and traversing water offer promise of usefulness. Sources of uncertainty in "limonites" are the resemblance between those derived from marmatitic ore and those from pure iron sulphides; variations in precipitation causing color and texture differences; and differences in the climate and topography affecting the precipitation regardless of intensity of the primary mineralization. Other clues that are at least moderately serviceable are: rock alteration, especially dolomitization, silicification, and argillization; associated topography, reflecting fracturing, solution, and collapse; and a geologic setting apparently favorable for deposition of primary ore, like an intrusive center for a possible ore halo. Common difficulties result from later, post-primary changes in land elevation affecting oxidation, and the removal or concealment of the surficial criteria mentioned by glacial erosion or by glacial or stream

deposits. A special difficulty is the dissimilarity between the surficial section of a given ore body and its deeper parts as to richness and volume of mineralization.

Illustrations of these principles are cited from Appalachian, Upper Mississippi Valley, Tri-State, Cordilleran, Mexican, and European districts.

*GEOLOGIC FACTORS LEADING TO NEGATIVE RESULTS IN EXPLORATION FOR ZINC AT WHITE PINE, TENN.**

ARNOLD L. BROKAW.

The planning of a mineral exploration program for a selected area is generally based on a theory or working hypothesis, deduced from available geologic data. If the exploration campaign is successful the hypothesis is given new and important stature in the field of exploration geology. If the exploration is unsuccessful, however, the theory generally is discarded as unworkable or at least inapplicable to the problem, and the search for new ideas concerning ore deposition continues.

Very few critical analyses of unsuccessful exploratory campaigns have found their way into the literature, although such studies undoubtedly are made by the geological staffs of the mining companies. Just as the deposition of ore in some mineralized areas is controlled by certain geological conditions, the absence of ore in other areas having similar geologic conditions must have a geological explanation. Analysis of the negative results in exploration should have an important bearing on the formulation of new ideas concerning ore deposition.

Study of the surface and subsurface geology in the East Tennessee zinc district indicated that the deposits are localized in favorable beds near the axial parts of folds where the folding was accompanied by fracturing and brecciation. In some places localization was directly related to high-angle faulting. The ore is believed to have precipitated from ascending solutions and the deposits were presumed to continue with depth. Heretofore if a zinc prospect was located in rocks stratigraphically higher than the formation generally considered more favorable for ore deposition, larger deposits were expected at depth. Drilling based on this theory failed to discover ore but rather conclusively showed that the mineral deposits did not persist downward. A re-evaluation of the geologic data in the light of this new information has led to the conclusion that although the ore is in places localized along faults, the stratigraphic position of ore bodies is controlled more by local structures favorable for the lateral spread of ore solutions. Factors controlling such a process would be (1) depth to which faulting extends, (2) location of zones of porosity due to fracturing and brecciation, and (3) the degree of porosity due to secondary dolomitization.

CASE HISTORIES OF RESISTIVITY APPLIED TO NEAR SURFACE GEOLOGY.

WILLIAM W. SCHWENDINGER AND WALTER J. GABRIEL.

The introduction consists of a short account of the theoretical principles underlying interpretational procedures and the instruments and techniques used to make the respective field surveys. Because of surface inhomogeneities and because of the tendency of a resistivity curve, caused by a two layer structure to appear as an apparent three layer curve, it is found necessary to use a statistically derived mean for the resistivity of the first or surface layer. An interpretation method for depth is given in which equi-resistivity contours are transformed directly into bedrock contours. The dominating features of each case history are outlined and the typical curves and their interpretations are included. For some case histories the type of overburden is the dominant feature, for others, geologic phenomena such as sink holes, nearness of bluffs and changes in soil resistivity give the greatest effects. Lastly, curves and results for three experimental resistivity surveys taken in the Mid-west are discussed.

* Published by permission of the Director, U. S. Geological Survey.

SCIENTIFIC NOTES AND NEWS

D. W. BISHOPP has resigned the Directorship of the Geological Survey of Ireland and has taken up an appointment as Senior Geologist to the Government of Cyprus, where a detailed geological and mineralogical survey has been started.

GEORGE PLAFKER resigned his position as engineering geologist with the U. S. Army Corps of Engineers, Sacramento, and is pursuing graduate studies in geology at the University of California.

WALTER C. STOLL has joined the Benguet Consolidated Mining Co., Baguio, Philippines.

FRANCIS A. THOMSON has resigned from the presidency of Montana School of Mines due to ill health. A. E. ADAMI, school vice-president, has been appointed acting president.

RALPH A. WATSON has been appointed assistant geologist, Great Northern Railway Co., Spokane, Wash. He was formerly field geologist for Anaconda Copper Mining Co., Butte.

SIR LEWIS L. FERMOR has been named President of the Institution of Mining and Metallurgy of London for the Session 1951–1952 and will take office next May.

The Southeastern Mineral Symposium will meet at Emory University in Atlanta, Georgia, on March 29–31, 1951. The Southeastern Geological Society will join with the Universities of Kentucky, Tennessee, Vanderbilt, and Emory. Geological papers relating to the Southeastern United States will be presented and field trips will take place. Please write Arthur C. Munyan, Chairman, for reservations at Department of Geology, Emory University, Georgia.

A Defense Minerals Administration has been set up in the Department of the Interior with Mr. James Boyd as Administrator. This organization will serve the mineral industry under the administration of the Defense Act of 1950. The Defense Minerals Administration, among other things, will act as claimant agency for the materials needed by the mineral industry, will attempt to expand mineral production, will carry on exploration on marginal properties, arrange for contracts for the purchase of minerals that may be brought out under marginal development, and will examine mineral properties. Members of the U. S. Bureau of Mines and U. S. Geological Survey will be stationed at the eight regular centers of the Bureau of Mines, from which centers they will conduct examination and exploration of mineral properties within the eight districts.

Behre Dolbear & Company have announced the appointment of ROLAND D. PARKS, of the Massachusetts Institute of Technology, as associate, and of F. BLONDEL, of Paris, France, and DR. TADISHIRO INOUYE, of Tokyo, Japan, as foreign consultants.

FRANK C. FOLEY, District Geologist, U. S. Geological Survey, Madison, Wisconsin, has been appointed Geologist and Head of the Division of Ground Water Geology and Geophysical Exploration, Illinois State Geological Survey, succeeding

Dr. Carl A. Bays, resigned, and as Research Professor of Geology, University of Illinois. This combined position will include state-wide research on ground water geology and the direction of graduate training in ground water geology at the University of Illinois. He will assume his new duties some time this spring.

The United States, United Kingdom, and Union of South Africa have concluded an agreement calling for production of uranium from South African gold-bearing ores. Uranium to be produced in the Union of South Africa as a by-product of gold production will be sold to the United States and the United Kingdom under an agreement just concluded by the three nations. The new agreement marks the successful culmination of several years of intensive research and development by the three nations on the problem of economically recovering uranium from the gold-bearing ores. The South African gold ores represent one of the world's largest sources of uranium. Although the uranium content of the ores is small, potential production is relatively large because of the great quantities of ore mined. The initial production will come from the properties of the following mining companies, although consideration will be given by South African Government to the construction of additional uranium processing plants on other mine properties as it is warranted: (1) West Rand Consolidated Mines, Ltd.; (2) Daggafontein Mines, Ltd.; (3) Blyvooruitzicht Gold Mining Co., Ltd.; (4) Western Reefs Exploration and Development Co., Ltd. Funds to cover the capital cost of the uranium processing plants will be loaned by the United States and United Kingdom, on a banking basis, if requested by the South Africans. Although uranium will be a valuable by-product of gold production, the revenue and earnings from uranium will not be on such a scale as to affect materially the financial positions of the companies concerned. Negotiations which led to the new agreement were concluded in December in Johannesburg by representatives of the three nations. Preliminary discussions were held in the same city a year ago. The principal representative of the United States at the meeting in December was Mr. Jesse C. Johnson, Manager of the Raw Materials Operations Office of the U. S. Atomic Energy Commission. Plant design and construction leading to the production of uranium under the new agreement is proceeding on an urgent basis. Because of security considerations, no information on rate of progress or other aspects of the program can be made public.

WALDEMAR F. DIETRICH has been appointed Chief of the Rare and Precious Metals Branch of the Minerals Division of the U. S. Bureau of Mines.

Geophysicists of the Geological Survey, Department of the Interior, using an airborne electronic device, have found a sunken barge loaded with steel beams specially fabricated for use on the new Chesapeake Bay Bridge. The barge was one of three that broke loose from their moorings near the bridge construction site, north of Annapolis, Maryland, during the early December gale. Two were readily found about 10 miles up the Bay, but the third disappeared completely and was believed sunk. Engineers of the bridge contractors sought to start an underwater search for the missing barge, which, if sunk in the Bay's main ship or ferry channels, might be a hazard to navigation. They met many difficulties and finally appealed to the U. S. Geological Survey, who, in view of the unusual circumstances, authorized James Balsley, in charge of a nearby project, to lend a hand. After plotting a series of traverses over a five-mile-wide section of the Bay, spaced 500 feet apart, they took off in a Survey magnetometer airplane. On the 10th traverse, the instrument registered a strong change in magnetic strength at considerable depth. A salvage tug was dispatched to the scene and divers were sent down to verify the magnetometer findings. The divers located the missing barge on December 16.

THOMAS S. LOVERING is Acting President of the Geological Society of America, following the recent death of Dr. Chester Stock, California Institute of Technology, who was elected president at the Washington meeting on November 18. Dr. Lovering will act as president until the Society council meeting scheduled for April, at which time a president will be chosen to serve the balance of the year.

LUTE J. PARKINSON, prominent mining consultant, was presented with the Colorado School of Mines Distinguished Achievement Award on December 15. Mr. Parkinson graduated in 1923 from the Colorado School of Mines, following which he worked for 20 years in Central and South Africa. In 1944 he worked in Brazil and then went to Chile where for the past five years he has been a mining consultant for the Anglo-Chilean Nitrate corporation and the Lautaro Nitrate Co., Ltd., of Antofagasta, Chile. His was the fifty-ninth award, which is given to graduates who make outstanding records in the mineral industries field, and who bring credit to themselves and the Colorado School of Mines.

PAUL W. ZIMMER resigned as geologist of the Chateaugay District, Republic Steel Corp. to accept a position as geologist for the St. Joseph Lead Co., Edwards Division, Balmat, N. Y.

C. DEWITT SMITH, formerly research and development engineer at the Southeast Missouri lead mining operations of St. Joseph Lead Co., has been made superintendent of mines at the company's Northern New York zinc mines at Balmat and Edwards, N. Y.

VERNON E. SCHEID, head of the department of geology at the University of Idaho, has been named dean of the Mackay School of Mines, University of Nevada. He has also been appointed director of the State Bureau of Mines.

NEIL O'DONNELL has resigned as executive vice president and general manager of Idaho Maryland Mines Corporation, Grass Valley, Calif.

HERBERT J. WILLSTATTER and ROLLAND L. BLAKE, 1950 graduates of the University of Minnesota, have been awarded research fellowships by the U. S. Bureau of Mines in a cooperative agreement with the University.

JESSE C. JOHNSON, manager, Raw Materials Operations, U. S. Atomic Energy Commission, returned from Johannesburg, South Africa, where he discussed with Union authorities the possibilities of production of uranium from South African gold-bearing ores.

F. E. WALLING has been appointed general manager in charge of Canadian operations of the Quebec Iron and Titanium Corporation, a subsidiary of Kennecott Copper Corporation.

K. K. DAR, formerly chief geologist for the Mewar Government, India, and later chief geologist and mining engineer for the late Rajasthan Government, has joined the Atomic Energy Commission of the Indian Government as mining geologist, with headquarters at Udaipur.

V. GORSKY has been made manager of a new mining company in North Transvaal, South Africa, the Incorporated Gold Mines, Ltd., P. M. B. Pietersburg.

C. A. BOTSFORD, mining consultant at Rome for the ECA Mission to Italy, has been transferred to the ECA Mission to Greece at Athens.